DECISION MAKER PERCEPTION OF INFORMATION QUALITY: A CASE STUDY OF MILITARY COMMAND AND CONTROL

by

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DEDICATION

This dissertation is dedicated to my family, without whom life would have no meaning.

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I would like to thank the many family, friends, and supporters who helped make this happen. Special hardships were borne by my mother, Penny, as she listened to my ideas month after month. Drs. Schum, Menasce, Laskey, and Sommer offered invaluable direction throughout my research. As with all research, I owe a tremendous debt of gratitude to Dr. Mica Endsley for both her encouragement in my own quest for knowledge and for literally creating situation awareness as a field of study. Finally, thanks go out to those in military service for graciously volunteering their time to participate in my work in the hope that it may one day improve their ability to make decisions under ever difficult conditions.

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ABSTRACT

DECISION MAKER PERCEPTION OF INFORMATION QUALITY: A CASE STUDY OF MILITARY COMMAND AND CONTROL

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Decision maker perception of information quality cues from an *information system* (IS) and the process which creates such meta cueing, or data about cues, is a critical yet un-modeled component of *situation awareness* (SA). Examples of common information quality meta cueing for quality criteria include custom ring-tones for specific numbers (relevancy), automated color changes on a computer display as inputs age (timeliness), and automated interface pop ups for missing information (completeness). In this work, I propose an information flow model incorporating feed-forward control (FFC) as a means to provide such meta-cuing for decision makers. The empirical basis for this information flow model was evidence collected from a case study of an IS dependent Department of Defense (DoD) global command and control (C2) center.

Currently accepted SA data flow diagrams suggest cues about our environment reach decision makers along one of three paths; *direct observation* via the decision maker's five senses, *indirect observations from another decision maker*, or *indirect*

observations of a system. One characteristic of indirect cueing is that contextual data, such as criteria for information quality (e.g., *accuracy, relevance, timeliness, usability, brevity, completeness, security, etc.*) normally associated with direct observation, are lost if not measured by a sensor or IS as data is created and then provided in conjunction with designed system output as meta cues.

Equally important for improved SA and decision making when using indirect observation is the use of meta cueing to indicate when required information quality criteria, such as accuracy, are not available and thus making the quality of the IS output unknown. Military lessons learned routinely document how user assumptions of information quality increase both the risk of SA error (e.g., misidentification of combatants) and decision maker distrust of systems which appear to provide poor quality information. Final end-states often include an unacceptable number and type of both mediocre and outright poor decisions, many of which lead to actions with unintentional and/or horrific outcomes.

This research describes the use of FFC produced information quality meta cues by decision makers restricted to a defined set of DoD information systems and applications providing indirect observations in support of their SA development and organizational C2. Despite no DoD wide requirements for FFC or information quality, I documented 19 unique and 49 instances overall of FFC induced information quality meta cueing. This evidence was collected through participation, interviews, surveys, and document reviews to assess the methodology, type, and frequency of FFC generated information quality meta cues. The case study provided evidence to support a novel model of decision maker perception of information using FFC meta cues as well as policies for implementation.

1. INTRODUCTION

On March 22, 2003, British Royal Air Force pilot Flight Lieutenant Kevin Main and his navigator, Flight Lieutenant Dave Williams, were killed instantly while returning from a successful mission in Baghdad when their Tornado GR4 aircraft was shot down by a U.S. Army Patriot battery which thought it was an anti-radiation missile (ARM).

Operating without their full communications suite, the battery relied on another battery for information from the battalion command center. Working autonomously, "the Patriot crew did not have access to the widest possible 'picture' of the airspace around them to build situational awareness," stated the British military incident report (2004).

As such, the Patriot battery was not in contact with air controllers who could have told them the Tornado was not a threat. In addition, the battery's tactical action officer (TAO) also lacked information about the fact no Iraqi aircraft capable of firing an ARM were flying and so such a threat was unlikely. With missing cues and poor perception, the TAO had less than a minute to decide whether to override the system or let it engage.

If the Patriot crew had had more information or even meta cues, information about information such as the quality of the cues their system was providing, and delayed firing for just a moment, the Tornado "would probably have been reclassified as its flight path changed" and the disaster avoided. As it was, the system had neither the inputs nor the capacity to provide such meta cues regarding the quality of the information at hand or its lack thereof to the TAO in those few seconds and so no override was ordered. It fired.

1.1 Command and Control

The Command and Control Center (C3)[1], is the nerve center for United States Major Command, responsible for the global situation awareness of the Commander, USMAJORCOM, and the mechanism by which they exercise operational command and control of global military forces. The C3 utilizes more than 300 distinct information management and communication systems which provide the USMAJORCOM commander an assured capability to manage Department of Defense (DoD) forces worldwide as directed by the President of the United States and the Secretary of Defense.

Information systems (IS) provide each decision maker in the C3 access to information essential to decision making and management of forces such as: adversary political, military, economic, social, and infrastructure information; Commander's Critical Information Requirements (CCIR); organizational data such as unit geographic locations, employment, readiness, composition, sustainment requirements; predictive intelligence on the operational environment; geospatial data; weather; etc. Synthesis of this information creates *situation awareness* (SA) for the Commander and others who use it to make critical decisions that often initiate inherently dangerous military actions.

While the military has a long history of decision making without the benefit of information quality cueing to provide improved perception of information quality, the networked information systems which provide most of a C3 decision maker's perception cues have the capability to facilitate such mitigation processes and prevent SA errors. Unfortunately, such capabilities are rare and, as with the Patriot TAO, quality is assumed.

Despite the military orientation of this research, the need for perception of information quality by decision makers is not unique to the DoD. Reducing decision maker uncertainty is a prerequisite for any task where high risk activities are coupled with an ability to do great harm as a result of actions initiated by poor decisions. Poor decisions are a well-documented byproduct of poor SA resulting from poor quality information. Yet despite these facts, the actual quality of the information utilized in the C3 to create SA and support decision making is largely unmeasured and unknown.

In this dissertation, I propose an information flow model incorporating the information meta cue creation process of *feed-forward control* (FFC). FFC attached in parallel to the system data flow path of an IS samples and compares information flow meta-data against a pre-determined list of decision maker task required criteria such as data quality, system credibility, IS pedigree, etc. Through the use of optional control actions, FFC may also help mitigate sub-standard information criteria provided by an IS <u>prior</u> to the information being provided to a decision maker (human or machine) as well as provide information attribute output meta cues about the system's information output.

1.2 Quality – The Information Metric

Information technology (IT) alters how decision makers perceive the world and military doctrine detailed in U.S. Joint Publication (JP) 6-0 *Joint Communications System* acknowledges the impact IT has on the quantity and speed we acquire environmental

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[1] C3 and U.S. Major Command are fictional names for the case study organization in this research.

data. *Information quality* is characterized by DoD as the criteria of *accuracy*, *relevance* *timeliness*, *usability*, *completeness*, *brevity,* and *security* listed in **Figure 1.1** below. JP 6-0 also point out how such information is highly susceptible to distortion and deception.

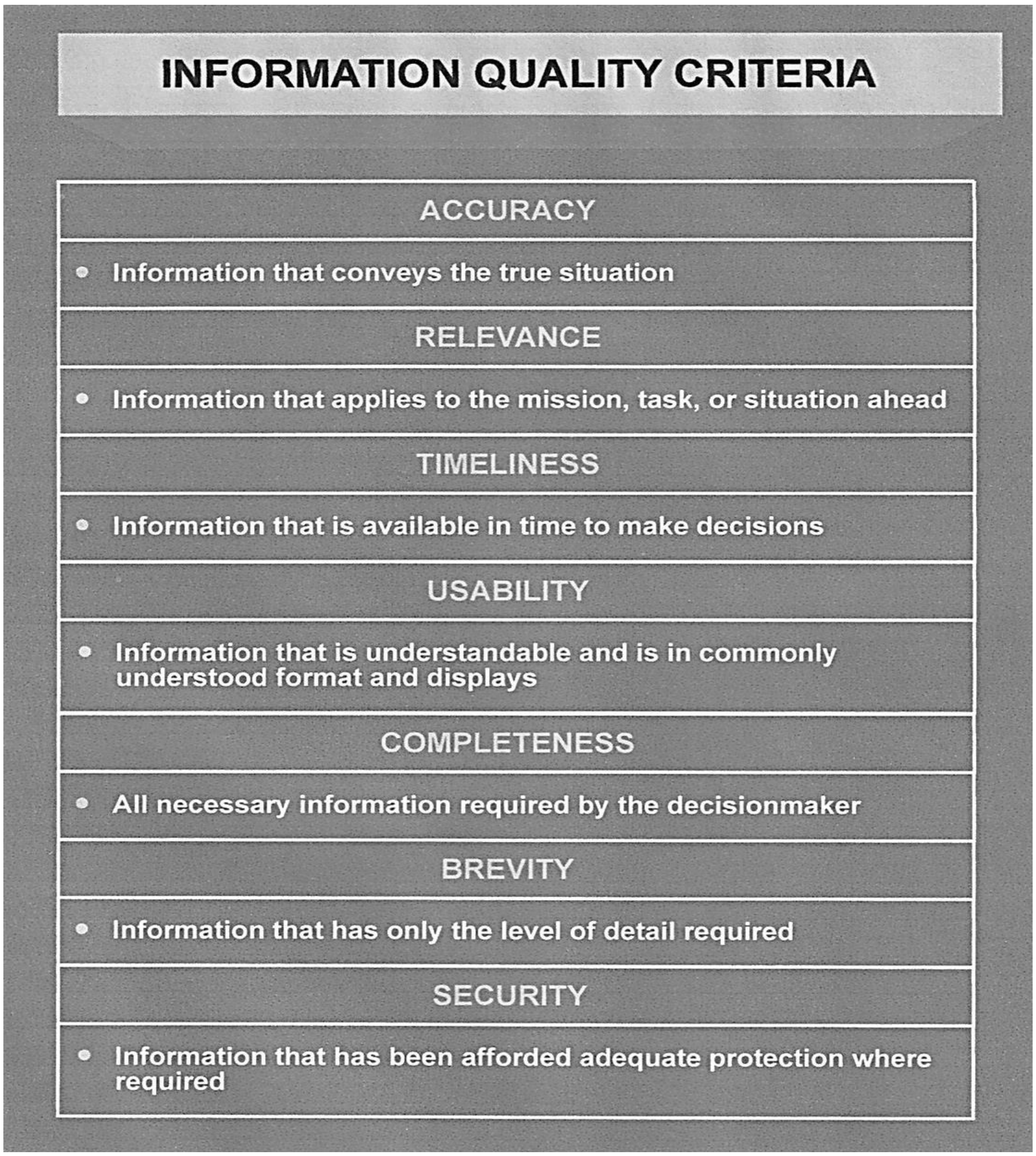

Figure 1.1 Information Quality Criteria (DoD Joint Publication 6-0, 2010)

Attribute indicators, provided as meta cues in parallel with system information output (e.g., text, images, audio, etc.), allow decision makers to put observations in context for a given task. These *perception-affecting factors* allow data to be translated into information and knowledge as part of the overall decision making process. As Endsley (2000) stated, "…a major challenge will be providing sufficient information thorough a remote interface to compensate for the cues once perceived directly."

Unfortunately, many of the information systems used by the DoD have attributes which are disturbing given the nature of military work: no policies requiring awareness of information quality, few quality cues to assist decision makers, and no documented mechanisms to even create the meta-data needed to provide such cues. While we may not always get what we want as far as quality, at a minimum we should know what we have. Given some of the dangerous tasks we use such systems to help us complete, when (not if) our increasingly complex information systems fail to provide the quality needed, we may not realize the need for quality cues until it is too late and the damage is done.

1.3 Perception – The Beginning of Situation Awareness

Perception, the first level in the *perception – comprehension – projection* process (Endsley, 1988, 1995), initiates creation of decision maker situation awareness. Although a notional example of various information sources, Endsley's SA data flow diagram (1995, 1997, 2000) is the only published example of flow paths. Her diagram in **Figure 1.2** suggests environmental cues reach decision makers along one of three paths; *direct observation* (e4) via the decision maker's five senses, *indirect observations from another decision maker* (e5), or *indirect observations provided by a system* (e3).

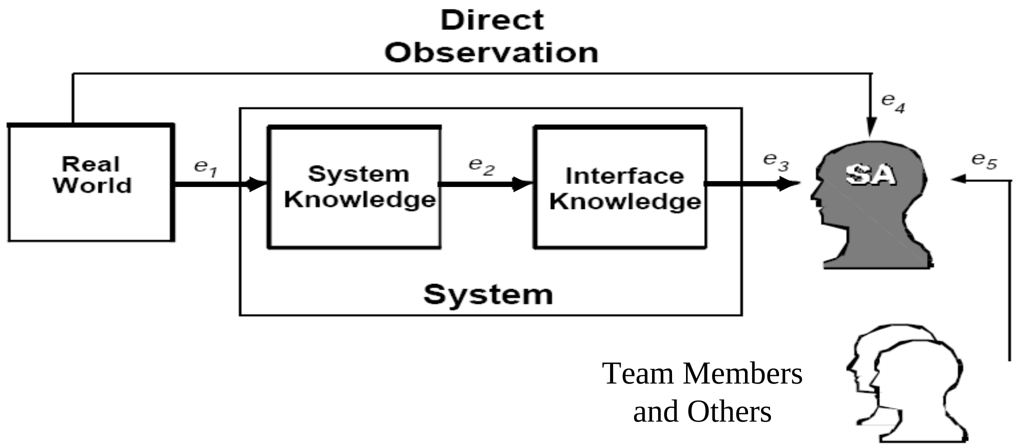

Figure 1.2 Situation Awareness Data Flow in System Design (Endsley 1995, 2000)

Regardless of the type of indirect observation system used, their ever expanding complexity, scope, speed, and output volume (e.g., a printed map verses a digital navigation device linked to an information network) greatly increases the probability of data which does not meet decision maker quality criteria existing within the system. Given that a loss of context is inevitable, we should ask what mechanisms are used to translate the ancillary evidence of information quality criteria from military doctrine into meta cues (e.g., visual, audible, and tactile indicators) to enhance user perception?

Without information quality criteria meta cueing processes based upon task requirements imbedded in our information systems, decision makers are provided with stark choices. One is to assume the data provided by our indirect observation system meets task requirements for quality, SA development, and decision making. Another is to employ limited resources (e.g., time, cognitive capabilities, etc.) to attempt such deductions while simultaneously conducting the assigned task. Neither of these choices is satisfactory given the rapid decision cycles most IS's support and limits on resources.

1.4 Feed-Forward Control – The Process that Provides Meta Cues

Feed-forward control, unlike feedback control where inputs are taken from the system output to deduce needed corrections, is the process which generates information quality criteria meta cueing. In **Figure 1.3** below, an environmental "Input" to a system sensor is sampled by the FFC process and compared against pre-determined "Output Requirements" in an effort to identify disturbances (e.g., differences between actual and desired input). This occurs <u>before</u> the disturbance is used by the system thus allowing FFC to mitigate via data removal or replacement and/or generate disturbance based "Cue" warnings. Such warnings are used to create "Meta Cues" in parallel with an associated system information "Output" (i.e., audio, visual, tactile). Decision makers are given both simultaneously to recreate context lost during the indirect observation process.

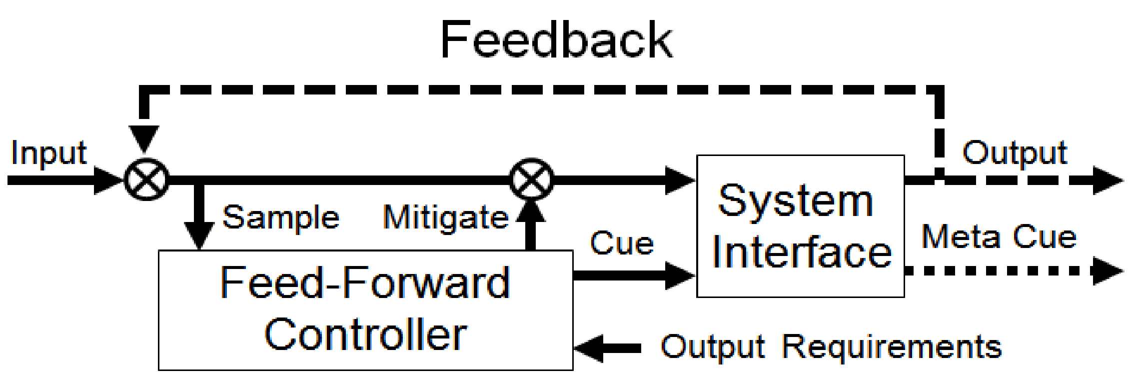

Figure 1.3 Feed-Forward and Feedback Control in a System

From the Patriot incident, system "Input" includes radar, communications, and other users' information processed and projected via an interface as "Output" for decision makers such as radar images, audible alerts, or text messages. "Meta Cues" would provide additional context using information attributes such as for the quality criteria of *timeliness* by color shifting images on the radar to show age based on user task needs (e.g., turns red if data older than 2 minutes), *relevance* by auto-selecting a desired portion of available radar data to project (e.g., area between 180 and 270 degrees), and *security* by toggling a status icon (e.g., green when data input is encrypted; red when not), etc.

Historically, FFC was first incorporated into physical systems (e.g., electrical, hydraulic, mechanical, etc.) utilizing disturbance detection and system input requirements to facilitate the application of corrective measures prior to the input reaching the system (e.g., increase voltage, decrease pressure, etc.). The secondary application of using FFCs to create decision maker meta cues for system input disturbances, such as quality in an information system, becomes profound in the context of enhancing a user's SA of the information attributes required as part of the system's output. **Figure 1.4** below further illustrates this supporting function of FFC alluded to in the Patriot missile example.

Example: Information Presented to a Decision Maker

SA ***without*** FFC Cues for Quality	SA ***with*** FFC Cues for Quality
- System projects a 360 degree radar map	- System projects a 360 degree radar map +
	- Information **accuracy**
	- Information **relevancy** (per example)
	- Information **timeliness** (per example)
	- Information **usability**
	- Information **completeness**
	- Information **brevity**
	- Information **security** (per example)

1.4 SA without and with FFC Meta Cues for Information Quality

1.5 Research Contribution

For this work, my goal has three objectives:

- *Present a novel information flow model describing decision maker perception of information with FFC*;

- *Document the use of feed-forward control (FFC) to generate information meta cues in a military command and control (C2) environment*; and

- *Recommend U.S. government policy changes to implement FFC.*

1.6 Problem Statement

Research by Orasanu et al (1993) and Endsley (1995) into the taxonomy of aviation based SA errors indicates that greater than 76% of SA errors occur at Level 1 SA – *perception of elements in the current situation*. **Figure 1.5** indicates that while there are a number of *cognitive* explanations for this type of error, the only type of *pre-cognitive* perception error is that in which relevant data about the environment (i.e., meta

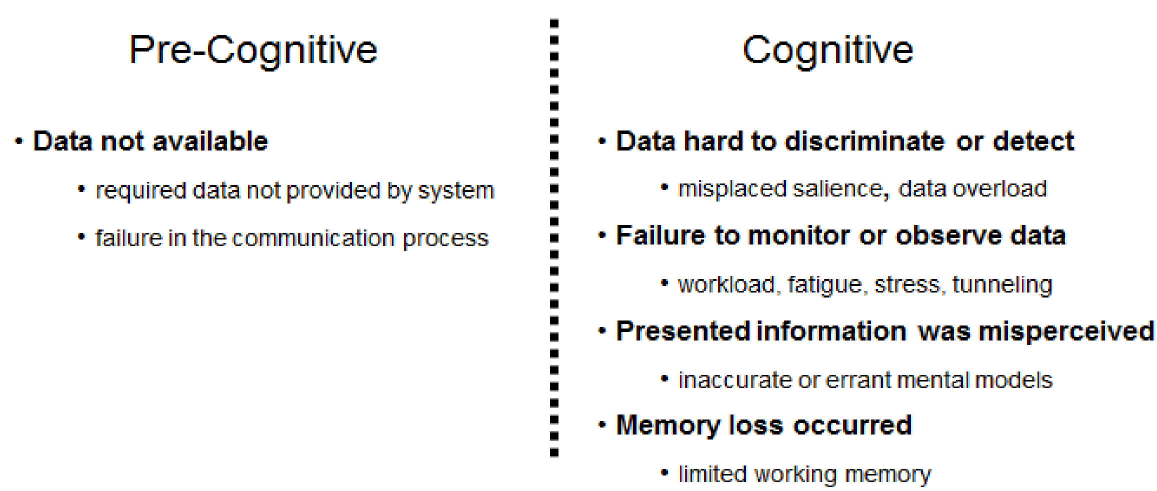

Figure 1.5 SA Level 1 Perception Errors by Type

cues for the information attribute of quality from criteria such as accuracy, completeness, timeliness, security, etc.) are not available to the decision maker “due to a failure of the system design to present it or a failure in the communications process” (Endsley 1995). Data unavailability accounts for 13% of Level 1 SA errors and 10% of SA errors overall.

Situation awareness errors by decision makers can lead to decision errors. Depending on the task being accomplished such as command and control of military forces, such perception errors can be catastrophic and cause loss of life. In the end, if SA is good and confidence is high, decision makers have a greater probability of achieving a positive outcome from their actions (Christ et al., 1994; Thomson et al., 2005)

1.7 Why This Is Important

The lack of decision maker SA regarding information quality is a three part issue. First, maintaining decision makers’ trust and confidence in their information systems is an uppermost concern in high stakes operational environments such as the military (Bisantz et al., 1999; McGuinness & Leggatt, 2006). Despite this observation, Kott et al. (2001) also found artificially high levels of uncertainty (i.e., where mitigation processes are available, but go unused) to be a leading factor in reduced decision maker accuracy.

Second, decision makers have cognitive limitations. I theorize (Morgan 2007, 2007a, 2012) decision makers are unable to distinguish between malicious and non-malicious changes in data within an information system. Once erroneous data is detected, a decision maker may default, incorrectly, to the belief that their system’s security has been compromised and attempt a mitigation process with even higher risks unless cues are provided which show a more detailed explanation for the erroneous data.

Third, military decision makers are experiencing a dramatic increase in data quality manipulation during exercises and actual conflicts with adversaries, but have few tools to assist them in determining quality. The Deputy Chairman of the Joint Chiefs of Staff released an updated instruction (U.S. DoD, 2011) which includes a significant expansion of *Red Team* capabilities, the training mechanism by which we "emulate a potential adversary's attack or exploitation capabilities against DoD ISs" in exercises.

Unlike traditional training in the warfare domains of air, land, maritime, and space which begins with warfighters mastering the fundamentals before moving through scenarios with progressively difficult environmental issues (equipment problems, increasingly skilled adversary, etc.) to promote problem solving, the U.S. military has a culture of "exercises and experiments that usually preclude or constrain free-play" on Red Team activities (Culpepper, 2004). This includes such actions as not allowing information quality corruption in the cyberspace domain during training that would disrupt, degrade, or destroy exercise C2 capabilities. The reason is that such corruption would impact the training objectives of the other domains (land, maritime, air, space).

The Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 6510.01 now states:

Constraints on Red Team operations should be for safety, real-world mission execution, and operations security, not for continuity-of-exercise operations, as a primary objective of Red Team operations is development of tactics, techniques, and procedures to "fight through" a degraded, compromised, or denied cyber environment.

Unfortunately, no DoD wide processes regarding the creation of meta cues to facilitate decision maker SA, policies requiring the use of FFC to create such meta cues, or requirements for the creation of quality meta data to feed the FFC process currently exist. Documenting the "as is" state of affairs as part of this research is a critical step towards developing improved process and mental models of the operational environment.

1.8 Research Question

Wickens and Hollands (2000) state, "…one quality of good decision makers is that they will often be aware of what they do not know." With that in mind as a guiding principle, the next logical step is to identify how good decision makers become aware of what they do not know. Years of academic research into this very question have led me to the conclusion that there is no model describing this process. As I am unable to identify any peer reviewed data or information flow models related to user situation awareness which include meta cueing for information quality, this research is targeted to answer the question:

How do decision makers perceive the quality of the information provided by information systems?

1.9 Research Hypothesis

Meta cues for information quality criteria, such as those specified in Department of Defense Joint Publication 6-0 Joint Communications System, are provided by feed-forward control (FFC) to military decision makers engaged in command and control (C2) activities as part of their situation awareness (SA) development process.

1.10 Research Approach

To acquire the evidence needed to document how decision makers perceive information quality, I employ a case study methodology and protocol with multiple evidence collection tools (e.g., participation, surveys, interviews, document reviews, etc.) to assess the output cues of indirect observation systems located in a major U.S. military command and control facility.

1.11 Scope of Research

The scope of this research is limited to documenting the mechanisms, policies, and requirements used by a major U.S. military command and control facility to provide decision makers with meta cues pertaining to the quality of the information provided by its indirect observation information systems.

1.12 Organization of Dissertation

This dissertation is organized as follows:

- **Chapter 2** summarizes the literature related to the topic area of this research dissertation to include decision making and situation awareness, key aspects of the problem statement, and feed-forward control;
- **Chapter 3** provides background on my research methodology, qualitative techniques for evidence collection, and case study implementation;
- **Chapter 4** provides the details of the evidence collection process and summaries of the results;
- **Chapter 5** includes analysis of evidence as well as lessons learned about the use of FFC and information quality requirements within the DoD;
- **Chapter 6** provides a description of my novel model and policy contributions;
- **Chapter 7** concludes with recommendations for future research.

2. LITERATURE REVIEW

As part of the research related to the problem statement, four specific topics are identified within this literature review; *situation awareness*, *military lessons learned, situation awareness risks,* and *feed-forward control*.

2.1 Theory of Situation Awareness

The late 1980's and early 1990's were a critical time in the development of situation awareness as both a theory and crucial construct to the decision making process. While related to key decision making processes such as selective attention, working and long-term memory, and response selection and execution, many researchers believed SA, as a process, to be distinct. As the ability of decision makers to complete complex cognitive tasks using dynamic information systems increasingly taxes the ability of humans to act effectively, possessing minimum levels of SA becomes critical.

Klein (1989) stated that an optimal theory of SA would explain attention to appropriate cues, dynamic goal selection, expectancies regarding future states of a situation, and the link between SA and decision making. Flach (1995) stated that SA calls attention to "meaning as a measure of what could or should be known in order to respond adaptively to the functional task environment."

Others such as Sarter and Woods (1995) believed the development of a definition for SA was not an effective research endeavor given the topic's broad interpretation at the time and increasing overuse as a term to describe a "a variety of cognitive processing activities" and unrelated human factors associated with human decision making.

Despite such varied opinions, Ensley's (1988, 1995) definition has been cited most extensively in peer reviewed literature and is generally acknowledged as the accepted standard. It states:

The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.

The three hierarchical phases of SA listed above were then linked to primary components of the complex decision making process and represented in Endsley's *Situation Awareness in Dynamic Decision Making* model in **Figure 2.1** below.

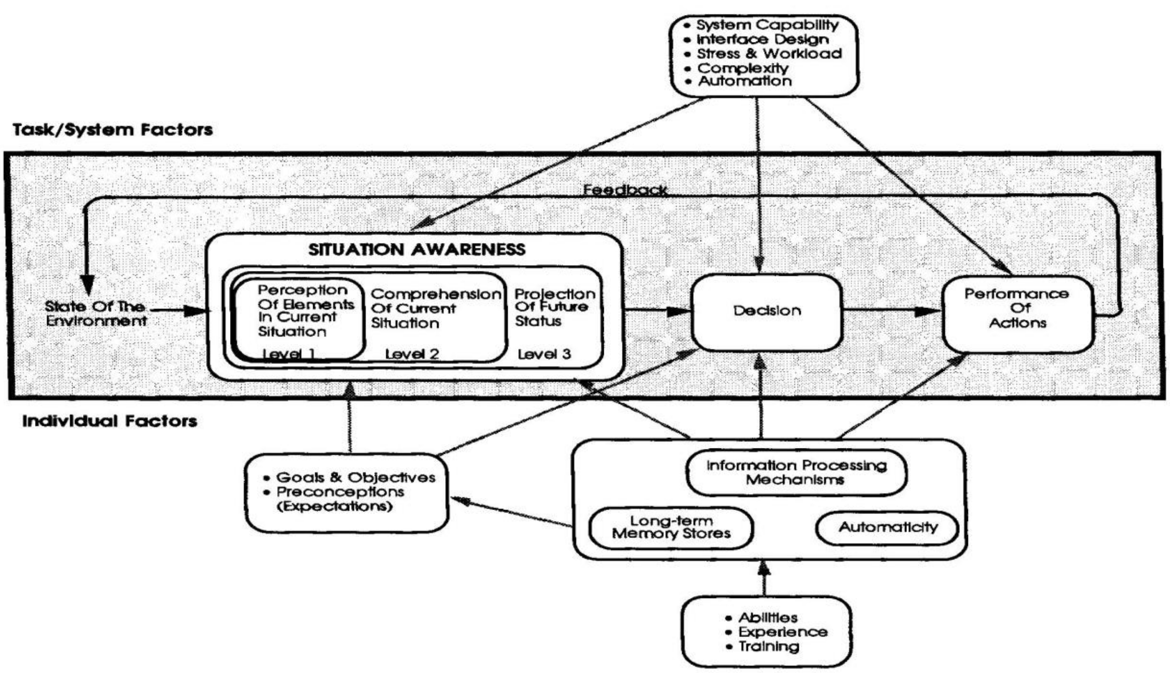

Figure 2.1 Situation Awareness in Dynamic Decision Making (Endsley 1988, 1995)

In her seminal 1995 paper for *Human Factors*, Endsley laid out her justification for the model. To avoid continued ambiguity, she was clear to note that SA does not encompass a person's complete knowledge, but "only that portion pertaining to the state of the dynamic environment." Additionally, her *Situation Awareness in Dynamic Decision Making* model confines the SA process to its own construct explicitly separate from decision making and other external factors. This rationale is easily proven by the common observation that individuals with very poor SA are still capable of making decisions capable of achieving desired outcomes just as those with very good SA are quite capable of making decisions resulting in poor if not horrific outcomes.

2.1.1 Level 1 - perception

Perception of the elements in the environment or "Level 1" within the SA box of **Figure 2.1** is the critical first step. Perception of "the status, attributes, and dynamics of relevant elements in the environment" include criteria such as color, size, speed, location, number, capabilities, and relationships (time, space, etc.) between the various entities.

For example, SA for effective decision making while driving your vehicle would include an ability to perceive that your speed is 60 MPH on a road where the posted limit is 45 MPH and that you are in the proximity of a police car. Should your speedometer be inaccurate, the speed limit sign missing, and the police car unmarked, perception and thus overall SA would be quite poor.

2.1.2 Level 2 - comprehension

During comprehension, a decision maker assembles "disjointed Level 1 elements" in an effort to understand the significance of these elements in the context of an objective or goal. The patterns that often emerge from this effort help form a holistic picture of the dynamic environment for the decision maker such as an ability to deduce the objective of other entities present, or determine the operating effectiveness of various machines and tools based on deviations from expected values. It is during this comprehension phase that exterior factors such as experience, training, and education can have a significant impact on a decision maker's abilities to comprehend.

Continuing the example, comprehension of the fact you are exceeding the speed limit in the presence of law enforcement is critical. One must be able to comprehend that speeding is punishable with a citation and that the objective of the police is to enforce the law. However, experience may indicate that the presence of other, more aggressive drivers may obfuscate your excessive speed or that the police in question are out of their jurisdiction and thus unable to enforce the traffic laws in this area.

2.1.3 Level 3 - projection

The ability to project future states of perceived elements, particularly "very near term" at a minimum, based on "knowledge of the status and dynamics of the elements" and an ability to achieve Level 2 comprehension is the final step in achieving situation awareness. Comprehensive SA provides decision makers the knowledge needed to choose "the most favorable course of action" necessary to meet one's goals or objectives.

For our example, a driver projecting that failure to limit speed by either reduced acceleration or increased braking would likely lead to an undesired confrontation with law enforcement and thus hinder the goal of avoiding a citation from said enforcement officials, as well as the high probability of associated fines, has a high level of SA.

Although failure by a decision maker to achieve any of the three Levels – perception, comprehension, or projection – undermines the full development of SA (i.e., missing or hidden speed posting, unfamiliar police car markings, belief you could outrun them, etc.), SA is but one factor contributing to the overall decision making process.

2.1.4 Additional factors

Task/System Factors at the top of **Figure 2.1**, which influence SA, decision making and the performance of actions per the diagram arrows, include such variables as:

- *System design (capability)* or "the degree to which the system acquires the needed information from the environment" or e1 per **Figure 1.2,** the amount of system data (e2) transferred to the interface, and the amount of interface information (e3) transferred to the decision maker;

- *Interface design* or "the way in which information is presented via the operator interface";

- *Stress* and *workload* or the level of physical and/or psychological stressors as well as such demands on the decision maker as to exceed their capacity;

- *Complexity* of the task needed to achieve the desired goal; and

- *Automation* of the process that may or may not improve the situation.

For example, a driver attempting to multitask along a poorly lit road on a rainy night using an inflexible multifunction navigation device may have their SA and decision making, as well as the actual performance of their actions negatively influenced by any one or combination of such variables if not properly implemented or mitigated.

Individual Factors at the bottom of the figure, which also influence SA and decision making and the performance of actions, include such variables as:

- *Goals* and *objectives* or the context and decisions for which SA is being sought;

- *Preconceptions* or *expectations* derived from experience in the environment which affect the speed and accuracy of information perception and "allows one to develop expectations about future events";

- *Cognitive limitations* (information processing mechanisms, long-term memory, and automaticity) associated with attention, perception, working memory, confidence levels, and automaticity, all of which are also derived from;

- *Abilities* that are both cognitive and physical;

- *Experience* in the environment; and

- *Training*.

An individual driving to a hospital will have different goals, which affect SA and decision making, than one going to work, and will act accordingly. It is also well documented that experienced decision makers are more likely to have improved SA over those with less experience or training in like situations.

2.1.5 State of the environment

The focus of this research is not the cognitive decision making process central to many decision making models, but the pre-cognitive data flow of environmental cues or evidence which provides the basis of decision maker perception. In **Figure 2.1**, it is apparent that the data flow between the *State of the Environment* and *Situation*

Awareness (Level 1) Perception is represented merely as a segment of the decision process feedback loop and indicates nothing more than the direction of data flow.

Noticing this oversight herself, Endsley later expanded this segment with the *Situation Awareness Data Flow in System Design* diagram (1995, 1997, 2000) based on her earlier work in situation awareness inputs (1990). See **Figure 2.2**. While this diagram provides a great deal of fidelity over the simple line segment between the *State of the Environment* and *Perception* in **Figure 2.1**, it uses the term "knowledge" in a way which conflicts with Cooper's model of *Cognitive Hierarchy and SA* (Endsley, 1997) .

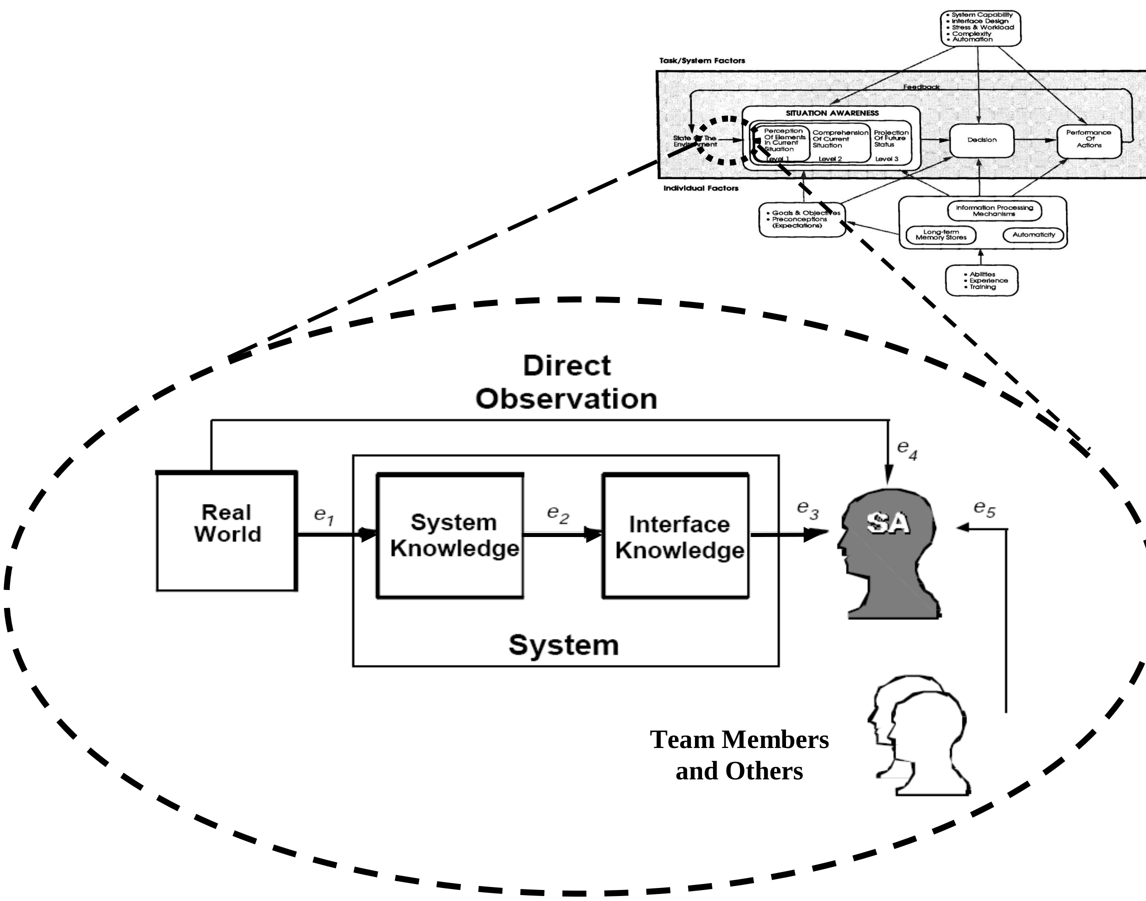

Figure 2.2 SA Data Flow as a Part of SA in Dynamic Decision Making

2.1.6 Situation Awareness Data Flow in System Design

The data flow diagram in **Figure 2.2** describes how cues from the real world reach the decision maker along not just one path as simplistically shown in **Figure 2.1**, but via one of three paths as depicted in Endsley's previously mentioned *Situation Awareness Data Flow in System Design* diagram in **Figure 1.2**. These pathways include an indirect observation system or series of systems (e3), direct observation via the decision maker's five senses (e4), and/or the observations of others (e5).

For example, direct observation as depicted via e4 could be simply looking at an event or object to receive direct observation visual cues (or scent, taste, touch, hearing, or combination cues). Both e3 and e5 are efforts to overcome human sensory and cognitive limitations while enhancing decision maker perception. Using the indirect observations of others as in e5 (i.e., What did you see/hear/feel/smell/taste on your way to work?) and those of the indirect observation information derived from e3 (i.e., systems as simple as a magnifying lens and as complex as the Hubble telescope) have expanded human SA to levels once unimaginable.

2.2 Military Lessons Learned

The impacts of poor decision maker perception of data quality on risk and uncertainty during military operations are reported at the Center for Army Lessons Learned (http://usacac.army.mil/cac2/call/ll-links.asp) and assessed by Morgan (2007a).

1st Marine Division (May 2003) – *Widespread use of the Secret Internet Protocol Router Network (SIPRNET) by authorized users to propagate poor quality data resulted in a loss of faith by commanders and created confusion and fear that was unnecessary.*

Multiple versions of overlays and human error in the Command and Control Personal Computer (C2PC) created confusion at all levels. Decision makers were inundated with intelligence information and data that had little bearing on their mission or requirements. There was also little confidence in the Modernized Integrated Database (MIDB) to provide general military intelligence, as it was often untrustworthy and resulted in decision makers choosing a periodic quality-controlled product over real-time erroneous information.

US Army Air Defense Artillery Quality Assurance Office (September 2003) – *Poor quality data created by the PATRIOT anti-air missile system and injected into the network degraded the overall air picture to the point where decision maker uncertainty over safety of flight became an issue and PATRIOT data was dropped despite being the only system capable of countering SCUD ballistic missiles.* See **Introduction**.

Marine Corps Systems Command Liaison Team (April 2003) – *Communicators, operations officers, and commanders routinely operated in information overload [poor brevity and relevance] as they received information over too many different networks. Statements on the Data Automated Communications Terminal (DACT) used to track force locations suggest low decision maker confidence due to poor reliability. Some instances reported units showing up in the wrong country or appearing miles away from their known locations.*

2nd Brigade, 101st Airborne Division (AASLT) (2003) - *The Blue Force Tracker (BFT) was unable to provide true unit locations for decision makers and rarely made data reported through the chain of command accurate or timely.*

3rd Infantry Division (July 2003) – *Data used by decision makers on secure Remote Workstations (RWS) became an inaccurate portrayal of the enemy situation. Secure communications available to the Intelligence Battlefield Operating System (IBOS) during Operation Iraqi Freedom (OIF) were insufficient to ensure timely, accurate, and relevant intelligence dissemination across the entire battlefield. Many secure intelligence systems were incapable of exchanging data with each other and those that could prove unreliable.*

Center for Army Lessons Learned (October 2003) - *As decision makers had to monitor multiple systems [up to seven] during combat operations and input data manually, the risk of uncertainty caused by errors [poor quality] increased dramatically.*

2.3 Situation Awareness Risks

The effects of SA errors cited above underlies a need to expand the Endsley data flow diagram with FFC in order to mitigate risks and uncertainty as meta cues for information quality can be more advantageous prior to a decision being made (FFC) than after using only feedback. Such misperceptions can cascade into SA errors and decision failure.

It should be noted that the perception shortcomings in the *Situation Awareness Data Flow in System Design* diagram coincide with Endsley's own research findings tying decision maker perception to the majority of SA errors in aviation incidents (Endsley, 1995, Orasanu, 1998). Specific problems identified in past research include:

- Perceptions errors between cues and desired data criteria (Steenkamp, 1990),

- Poor perception of actual data quality (NIST CLS Bulletin, 1994; Endsley, 2003),

- Inaccurate mental models of the data flow process (Besnard et al, 2004).

2.3.1 Poor perception of actual data quality

The impact of data quality on networked information systems used for indirect observation is well documented and ranges from research confirming the high likelihood of inconsistencies in information systems as a result of overlapping databases (Motro et. al., 2004), to the cascading effect of both data and application problems within network centric data flow environments (Khalilzad, 1999; Bass & Robichaux, 2001).

These studies confirmed that poor quality data and application failures linked to such data not only migrate throughout a networked information system, but they also have a multiplying effect leading to even greater problems than originally observed. Data quality data failures are documented so frequently as to form entire information assurance risk domains (Baker, 1993; Abrams et. al., 1995; Bass & Robichaux, 2001).

Research in the field of data quality modeling shows that, like quality control in manufacturing, poor quality data has a cost associated with it that is best overcome by the building of quality controls directly into data flow processes (Readman, 1995; Wang et. al., 1992). An important factor to consider in this regard is that data quality standards required by decision makers are situational and often in conflict with each other (Fry & Sibley 1976, Labbe 1999, Arnborg et al., 2000; Cirincione et al., 2010; Bar-Noy et al., 2011).

When this is the case, it is recommended that decision makers specify the quality data characteristics most important to them in the context of their environment and mission requirements (Hazen, 2004).

2.3.2 Perception errors between evidence and desired data criteria

Literature also indicates decision makers utilizing information systems for indirect observation have a limited capacity to detect such risk parameters, although the use of quality data incentives and risk expectations from error rates have shown an ability to improve this capability (Laudon, 1986; Ricketts, 1990; Kline, 2000). Regardless of the source of the vulnerability or the threat capable of exploiting it, studies on the impact of data quality to user confidence highlight both the uncertainty risk present in the situation awareness of decision makers and just how poorly calibrated user confidence is to actual data quality (CLS Bulletin, 1994; Endsley, 2003).

2.3.3 Inaccurate mental models

Mental models help decision makers simplify and organize complex conceptual and physical aspects of the environment, mainly as a result of limited memory and cognitive processing capabilities (Besnard, Greathead, & Baxter, 2004). Mental models are best characterized as only partial representations of the environment with limited scope (Sanderson, 1990; Sanderson & Murtagh, 1990). In fact, researchers generally believe that mental models are perceptually based and decision makers create similar models from both direct and indirect environmental data (Bryant, 1992).

The use of flawed mental models by decision makers such as medical personnel, aircraft operators, or military C2 personnel interacting with dynamic critical systems can be disastrous. According to Besnard et al. (2004), the weakness of mental models lays in their poor requirements for validity. If the environmental stream of data is consistent with the decision maker's expectations, such coincidence is often used to falsely validate the flawed model. Thus, understanding the mechanisms behind the data generations becomes unnecessary and the cycle of risk continues.

Another reason for the reinforcement of flawed mental models is the phenomenon of confirmation bias (Klaymand & Ha, 1989) which allows decision makers to save cognitive resources by overlooking data contradictory to their mental model. This bias is more likely in highly dynamic environments where decision makers will significantly reinterpret data in order to make it fit the situation (Moray, 1987).

2.4 Feed-Forward Control

First proposed by Ashby (1956) as a process to improve control over systems, *feed-forward control* (FFC) senses and takes specific actions regarding disturbances within a system's inputs based on predetermined input minimum and/or maximum values for desired output requirements. See **Figure 2.3**.

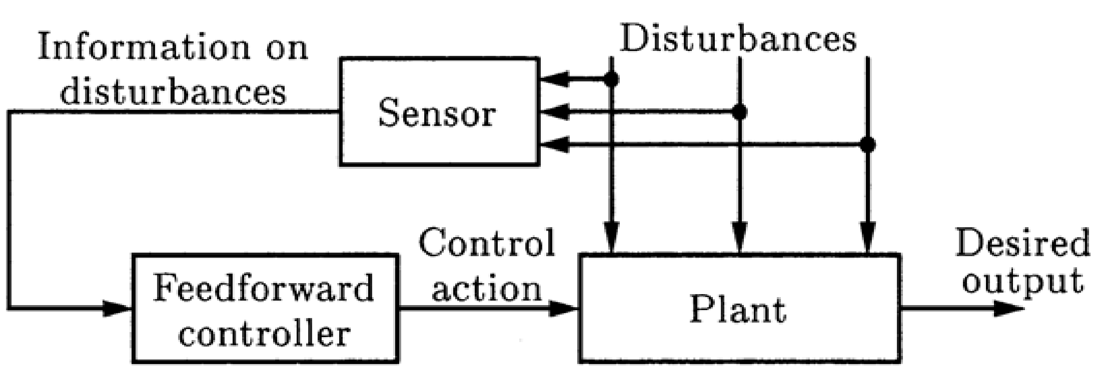

Figure 2.3 Feed-Forward Control Model (Kabamba et al., 2002)

The input requirements stored in the *feed-forward controller* are either hardwired or injected (not shown). When input *disturbances* detected by the *sensor* exceed the values in the controller, the controller sends a *control action* to the *plant* or process area of the system. The specifics of the control action can vary widely depending on the process being executed in the plant.

For example, if 1 gallon per minute were the desired output of the system, a flow rate of 1 gallon per minute on the input may be required to prevent damage to the system or injury to the user. This input requirement is stored in the feed-forward controller. At some point the FFC sensor may detect a disturbance – the input flow rate has fallen to .9 gallons per minute. Information on the disturbance is then sent to the feed-forward controller where the control action of injecting .1 gallon per minute of fluid into the plant is initiated to mitigate the .1 gallon per minute input disturbance.

Such control actions can be numerous and varied. For the example above, the feed-forward controller could also generate a signal or meta cue about the status of the input based on user requirements. Or, the meta cue could be the only control action taken depending on the design of the system.

Most topics of study in the area of FFCs have been with industrial or engineering applications (Seborg et al, 1989; Shinskey, 1996; and Marlin, 2000). Lerch and Harter (2001) used FFC in cognitive support systems to project future states of the system in an effort to reduce the cognitive workload of the decision maker. Brosilow and Joseph (2002) researched effects of an internal system disturbance and demonstrated that FFC could reduce disturbances better than feedback alone.

Also, research involving a feed-forward model based on the predictability of disturbances incorporated into artificial neural networks has been documented (Kowalski, 2001; Alexander, 2004). It must be noted that the lack of formalized research involving FFC within ISs has not prevented their development or employment in the commercial sector. A case in point is the unintentional use of FFC by Oracle in **Figure 2.4** to create an optional “Data Quality and Profiling” process within their Ideal Exadata Reference Architecture.

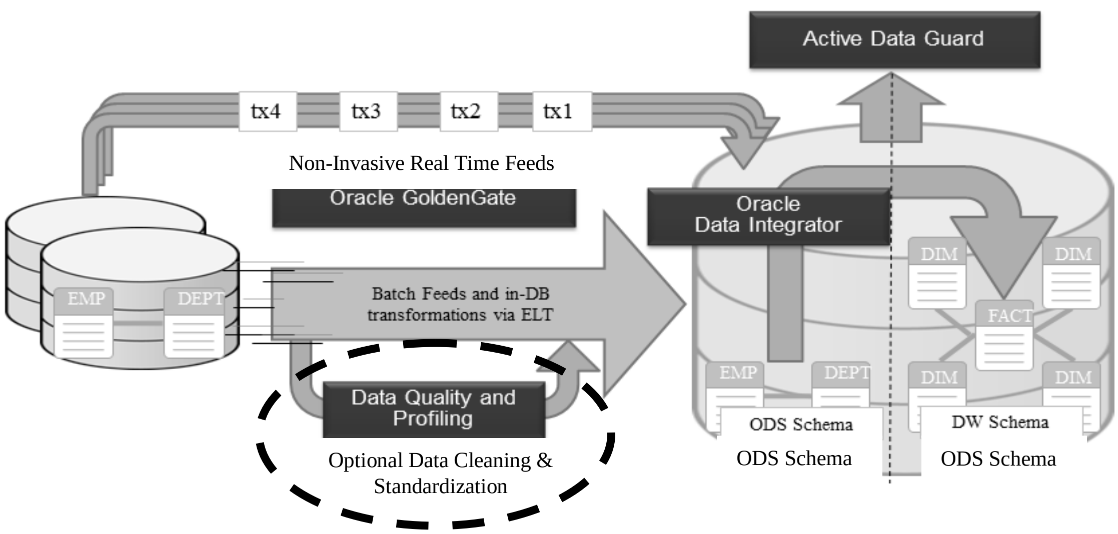

Figure 2.4 Oracle Ideal Exadata Reference Architecture (with permission)

As shown within the dashed oval, Oracle uses the FFC process to monitor data base information quality during internal data base transformations and batch feeds to data integrators for quality anomalies. While reference material from Oracle indicates data quality anomalies are mitigated with corrective data replacement when possible, no mechanism within their use of the FFC process indicates it also provides information quality meta cueing. Additionally, correspondence with Oracle regarding the nature of their Data Quality and Profiling process indicated they had no knowledge of FFC in an information system as a formal systems engineering process nor did they provide a systems engineering based rational for their process other than the desire to improve information quality.

Despite these indications of FFC usage to correct data quality anomalies or provide evidence of information quality via the generation of information quality meta cues, the use of FFC within ISs, to either mitigate disturbances or create indicators, is neither documented or alluded to by Endsley in her SA data flow diagram.

3. RESEARCH METHODOLOGY

The method followed for conducting this qualitative research was the collection and analysis of data in support of a descriptive case study.

3.1 Qualitative Techniques

Selection of a research methodology to facilitate an assessment involving SA data flow in system design was the first stage in the overall dissertation design. A variety of research methods are recognized by the information systems community under the two main categories of quantitative or theory driven (e.g., survey, laboratory experiments, formal, and numerical) and qualitative or data driven (e.g., action research, case study, and ethnography) (Myers, 1997). Due to the difficulty associated with attempting to isolate, recreate, or control the military C2 activity being studied in my research as would be required for structured or formal quantitative methods, I have chosen a qualitative technique utilizing a case study methodology.

In the field of information science, the suggestion by Franz and Robey (1984) to use idiographic research strategies to understand phenomena within a concrete or unique environmental context is also supported by my use of the case study methodology. The characteristics of such strategies in qualitative research include:

- Data gathering usually tied to less structured research instruments such as my use of observations, surveys, and interviews;

- Findings that do not require use of a control group to understanding the underlying complexities of military C2 processes;

- Results acquired through the "researcher's immersion" in the organizational culture to better understand particular human-technology interaction within the context of its natural environment; and

- Research that is more intensive, as both a member of the case study organization and a research observer, and flexibility greater than standard experimentation such as altering the timing, sequence and tools used to collect observations.

3.2 Case Study Research Design

Benbasat et al (1987) and Yin (2009) both describe key characteristics of the case study research method I have selected for this research and both find it is well suited to issues related to decision maker utilization of information systems, as is the situation with my case involving military C2. Several of their reasons for utilizing case studies include:

- Researchers can study systems in a natural setting and generate theories;

- It allows the researcher to answer "how" and "why" related to complex processes; and

- It is an appropriate research method where few previous studies have been done.

All three of these reasons align well with my research objectives. First, the research goal of presenting a new information flow model is dependent upon an ability to observe and document existing information flow processes in their natural environment in order to assess the newly developed theories associated with my proposed information flow model. Second, my research question is "how" based and tied to a complex IT based indirect observation process that must be understood and documented. And third, there is little known research identifying previous studies of FFC to facilitate decision maker perception of information quality in any context, military or civilian. **Table 3.1** below lists characteristics of case studies summarized from multiple research papers, all of which apply to this case study.

Table 3.1 Key Characteristics of Case Studies (Benbasat et al, 1987)

1. Phenomenon is examined in a natural setting.
2. Data are collected by multiple means.
3. One or few entities (person, group, or organization) are examined.
4. The complexity of the unit is studied intensively.
5. Case studies are more suitable for the exploration, classification and hypothesis development stages of the knowledge building process; the investigator should have a receptive attitude towards exploration.
6. No experimental controls or manipulation are involved.
7. The investigator may not specify the set of independent and dependent variables in advance.
8. The results derived depend heavily on the integrative powers of the investigator.
9. Changes in site selection and data collection methods could take place as the investigator develops new hypotheses.
10. Case research is useful in the study of "why" and "how" questions because these deal with operational links to be traced over time rather than with frequency or incidence.
11. The focus is on contemporary events.

While there is no standard definition of a case study from which I can draw specific guidance, several common themes are found in existing research (Stake, 1994; MacNealy, 1997) and Benbasat et al combined them to produce the definition:

A case study examines a phenomenon in its natural setting, employing multiple methods of data collection to gather information from one or a few entities (people, *groups, or organizations). The boundaries of the phenomenon are not clearly evident at the outset of the research and no experimental control or manipulation is used.*

This definition clearly represents key characteristics of my research topic and goals. Bendasat et al also point out that the use of case study methodology is not always clear-cut and it may be applicable to various phases of research. As such, they created a table to place aspects of the case study methodology in context with the terminology for traditional exploration, hypothesis generation, and the testing phases associated with knowledge discovery. See **Table 3.2**. As my case study is limited to a single case, a U.S. military C2 facility, such a table helps cross-walk my research methodology towards the criteria needed for a descriptive case study as stated at the beginning of this chapter.

Table 3.2 Terminology for Stages of Case Study Research (Benbasat et al, 1987)

Traditional Phases of Knowledge Accrual	Yin's [56] Framework	Bonoma's [5] Framework	Number of Cases
Exploration	Description	Drift	Single or multiple case(s)
Hypothesis generation	Exploration	Design	Multiple cases
Hypothesis testing			
• Confirmation	Explanation	Prediction	Multiple cases
• Disconfirmation	Explanation	Disconfirmation	Single critical case

Both Yin and Bendasat also offer recommendations for implementing case study research which denote the special attention I must pay in my own decision maker perception of information topic regarding the following areas; *unit of analysis*, *single case vs. multiple case design*, *site selection*, and *data collection methods*.

3.2.1 Unit of analysis

It is essential that the most appropriate unit of analysis for the research such as a study of individuals, groups, organizations, a project, or a decision be selected. As such, the unit of analysis for this research is the individual decision maker operating within a military command and control facility. This determination is tied directly to my research question, "*How do decision makers perceive the quality of the information provided by information systems?"* (see **paragraph 1.7**) which provides explicit guidance for the selection of an appropriate unit. Another key element in my choice of individual military decision makers is the desire for greater generalizations of the research results as the characteristics of these watch standers are easily transferable to similar watch standers.

3.2.2 Single case vs. multiple case design

As a researcher using the case study methodology to develop theory, I must also assess the appropriate number of cases (single or multiple) in my research design to aid external validity. I selected a single case design due to my unique situation which allowed me to be the first researcher in the long history of USMAJORCOMMAND granted permission to "explore a significant phenomenon under rare or extreme circumstances" (Eisenhardt and Graebner, 2007); namely global C2 of military forces. While intermediary C3 decisions may seem mundane (logistics, force deployment, etc.), all actions coalesce around the use of deadly force which could impact millions. While **Table 3.2** shows multiple case design to be the most common (Yin, 1984), a single case study such as using a single military facility is acceptable only if:

- The case is revelatory in that the situation was inaccessible to research;
- The case is critical in that it challenges, extends, or confirms a documented theory; or
- The case is extreme or somehow unique.

To enhance validity, I ensured all three of these conditions are present in this research in that the high security classification greatly limits access provided to the C2 facility, my research intent is to challenge and extend Endsley's existing data flow paths for SA, and the case's unique mission. The fact the observed systems are used throughout DoD with uniform policies further increases validity.

3.2.3 Site selection

Researcher site selection is automatic in a single case design per Yin (2009).

3.2.4 Data collection methods

According to Benbasat et al, multi-source data collection is ideal and the evidence collected should converge to support the research findings and be collected in such a manner as to allow for others to easily understand. Yin makes similar recommendations regarding several sources that have worked well in case studies and that I use here:

- Documentation in the form of written material;
- Archival records such as annual reports, financial records;
- Interviews structured as either open ended or focused (Bouchard, 1976);

- Direct observation noting details, actions, subtleties of field environment; and

- Physical artifacts such as devices or tools.

All of these recommended evidence collection tools, with the exception of archival records, are used in my research. This includes both a formal survey and a focused interview, along with documentation of quality meta cue requirements. These collection tools, in conjunction with my direct observations as both a researcher and a participant, are designed to provide for maximum convergence of collected evidence.

3.3 Criteria for Judging the Quality of Research Designs

There are a number of concepts to test the quality of a given research design, but Yin (2009) has identified the four most often used to assess the quality of empirical research such as case studies. **Table 3.3** summarizes the concepts while listing both the tactic recommended for implementation and the research phase in which it occurs.

Table 3.3 Case Study Tactics for Four Design Tools (Yin, 2009)

TESTS	Case Study Tactic	Phase of research in which tactic occurs
Construct validity	◆ use multiple sources of evidence	data collection
	◆ establish chain of evidence	data collection
	◆ have key informants review draft case study report	composition
Internal validity	◆ do pattern matching	data analysis
	◆ do explanation building	data analysis
	◆ address rival explanations	data analysis
	◆ use logic models	data analysis
External validity	◆ use theory in single-case studies	research design
	◆ use replication logic in multiple-case studies	research design
Reliability	◆ use case study protocol	data collection
	◆ develop case study database	data collection

All four of the tests are applicable to this particular research design; *construct validity* through my use of multiple sources of evidence (see **paragraph 3.2.4**); *internal validity* through my analysis of rival explanations of information quality meta cue creation, *external validity* through the assessment of information systems, policies, and tools used broadly throughout the DoD among multiple Services, Agencies, and commands; and *reliability* through my use of a case study protocol involving easy to replicate evidence collection processes and the consistency of a single researcher for evidence collection.

4. EVIDENCE COLLECTION

Evidence collection methods for this research consisted of document reviews, direct and participant observations on the part of the researcher, and both surveys and focused interviews with decision makers assigned to the facility. Two-star general/flag officer approval was required. Due to the use of human subjects, approval of collection tools by George Mason University's Office of Research Subject Protection was obtained.

Yin (2009) stresses the importance of research design at the outset of a case study as a mechanism to enhance the quality of the research. Construct validity and reliability, two of the research quality tests discussed in Chapter 3, becomes critical in the evidence collection phase. Validity, the use of multiple sources of evidence to create convergent lines of inquiry, and reliability, the ability to assess the same case over and over again through the use of a case study protocol to minimize errors and bias, begin with proper operational measures of information quality followed by uniform research execution.

4.1 Evidence of Operational Measures and Cue Requirements from Documents

4.1.1 Joint Publication 6-0 Joint Communications System (2010)

Joint Publication (JP) 6-0 is but one of a series of publications issued under the direction of the *Chairman of the Joint Chiefs of Staff* (CJCS) which establishes joint doctrine used to govern the activities of the Armed Forces of the United States. While not originating from the President or the *Office of the Secretary of Defense* (OSD), such doctrine is authoritative in nature and applies to all commanders of *combatant commands* (COCOMs), sub-unified commands (e.g., U.S. Cyber Command), *joint task forces* (JTFs), subordinate components of these commands and the Services (e.g., U.S. Army, U.S. Navy, U.S. Marine Corps, and the U.S. Air Force). Per the introduction of JP 6-0:

No single activity in military operations is more important than C2…In one way or another, C2 is essentially about information: getting it, judging is value, processing it into form, acting on it, and sharing it with others. There are two basic uses for information. The first is to help create situational awareness (SA) as the basis for a decision. The second is to direct and coordinate actions in the execution of the decision.

Key to understanding the term *situation awareness* is defining the information environment. The DoD has expressed it as an aggregate of all the environmental components such as the systems, individuals, and organizations that collect, process, analyze, apply, disseminate, or act on information. Thus, the information environment within the Department of Defense is the principal environment for decision making.

The DoD information environment consists of three unique dimensions. They include the *physical* which encompasses command and control systems and supporting infrastructure such as information networks; the *cognitive* which occurs within the mind of the decision maker and includes the development of situation awareness; and the *informational* where key aspects of content, flow and quality in collection, processing, storage, dissemination, and display drive modern military C2. See **Figure 4.1**. The informational dimension acts as a bridge between the physical and the cognitive.

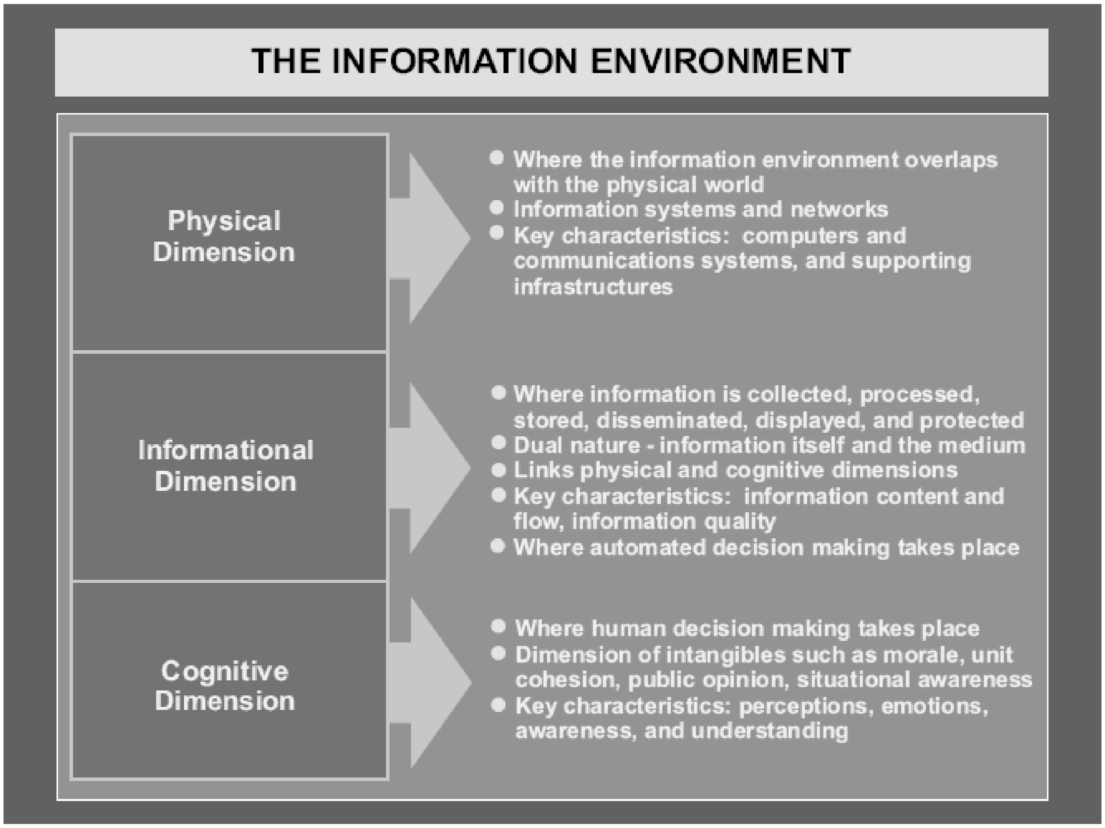

Figure 4.1 The Information Environment (DoD Joint Publication 3-13, 2006)

Furthermore, the informational dimension characteristic of *information quality* drives the development of operational measures, measures critical for the creation of information quality meta cues to support situation awareness. Known as *information quality criteria*, these measures can thus be used to identify DoD information quality requirements in the documentation associated with C2 and DoD information systems.

The seven DoD information quality criteria of *accuracy, relevance, timeliness, usability, completeness, brevity,* and *security* are distinct and unique (see **Figure 1.1**); however, they are not equal as each is subject to dynamic task based weighting by the user. Quality criteria vary by organization or task so this list is not exclusive (Agre et al., 2011).

4.1.2 Network Centric Operations Conceptual Framework V.1 (2003)

The now defunct *Office of Force Transformation* (OFT) and the *Office of the Assistant Secretary of Defense, Networks and Information Integration* (OASD/NII) developed a *Network Centric Operations Conceptual Framework* (NCO CF) that identified key concepts of the theory and linkages to output measures in the Network Centric Warfare value chain in the context of the physical, information, cognitive and social domains (i.e., “dimensions” per the later JP 3-13). See **Figure 4.2**.

The top level concepts identified in this value chain provide shows the Quality of Organic Information (i.e., information derived from or gathered by an entity that is not shared and is initially unavailable to the network) injected into the situation awareness and decision making process on equal footing with Quality of Networking inputs.

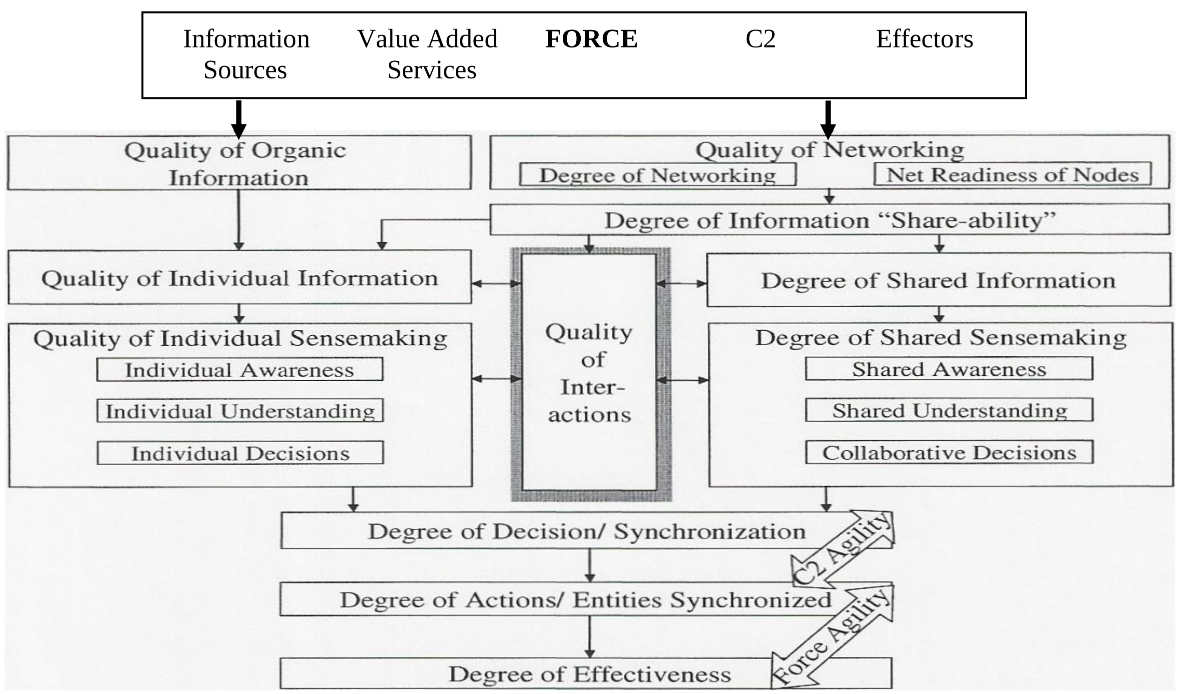

Figure 4.2 NCO Conceptual Framework (NCO CF V1.0, 2003)

Initially described as a work in progress incapable of providing criteria on what to do to enhance NCO or how to do it, the conceptual framework does facilitate the collection of evidence in the form of attributes and metrics for each of the top level concepts. For Quality of Organic Information and Quality of Individual Information (i.e., Organic Information plus Shared Information that is distributed over a network and obtained through some interaction), these include fitness-for-use attributes and quality criteria such as *accuracy, timeliness, relevance,* and *completeness* (four of the seven quality criteria found in JP 6-0) along with objective attributes such as currency, precision, consistency, and correctness. See **Table 4.1**.

Table 4.1 Quality of Organic Information (NCO CF V1.0, 2003)

Attribute	Definition
Objective Measures	Measures quality in reference to criteria that are independent of the situation
Correctness	Extent to which information is consistent with ground truth
Consistency	Extent to which information is consistent with prior information
Currency	Age of information
Precision	Level of measurement detail of information item
Fitness for Use Measures	Measures quality in reference to criteria that are determined by the situation
Completeness	Extent to which information relevant to ground truth is collected
Accuracy	Appropriateness of precision of information for a particular use
Relevance	Proportion of information collected that is related to task at hand
Timeliness	Extent to which currency of information is suitable to its use

4.1.3 Department of Defense Net-Centric Data Strategy (2003)

Net-centricity, the realization of a networked environment including systems, infrastructure, processes, and people, is a data management paradigm under continuous implementation by the DoD to improve military situation awareness and thus decision making through a strategy of increased data *visibility* and *accessibility* by military decision makers. See **Table 4.2**.

Table 4.2 ***Department of Defense Net-Centric Data Strategy*** **Data Goals**

Goal	Description
Goals to increase Enterprise and community data over private user and system data	
Visible	Users and applications can discover the existence of data assets through catalogs, registries, and other search services. All data assets (intelligence, nonintelligence, raw, and processed) are advertised or "made visible" by providing metadata, which describes the asset.
Accessible	Users and applications post data to a "shared space." Posting data implies that (1) descriptive information about the asset (metadata) has been provided to a catalog that is visible to the Enterprise and (2) the data is stored such that users and applications in the Enterprise can access it. Data assets are made available to any user or application except when limited by policy, regulation, or security.
Institutionalize	Data approaches are incorporated into Department processes and practices. The benefits of Enterprise and community data are recognized throughout the Department.
Goals to increase use of Enterprise and community data	
Understandable	Users and applications can comprehend the data, both structurally and semantically, and readily determine how the data may be used for their specific needs.
Trusted	Users and applications can determine and assess the authority of the source because the pedigree, security level, and access control level of each data asset is known and available.
Interoperable	Many-to-many exchanges of data occur between systems, through interfaces that are sometimes predefined or sometimes unanticipated. Metadata is available to allow mediation or translation of data between interfaces, as needed.
Responsive to User Needs	Perspectives of users, whether data consumers or data producers, are incorporated into data approaches via continual feedback to ensure satisfaction.

Although the goals of increased visibility and accessibility are supportive of general situation awareness theory, the Strategy's goal of enhancing data visibility though the use of meta-data makes no mention of a need or requirement to utilize meta-data for information quality criteria as part of the overall Strategy. At this point, there appears to be a disconnect between the Strategy's definition of quality criteria compared to that used in JP 6-0 as the goals of both understandable (i.e., usable) and trusted (i.e., secure) data are information quality criteria despite the fact the Strategy goes on to discount the need for operational measures for information quality by stating:

Data quality and accuracy will be improved as a consequence of the above data goals; making data more visible and usable across the Enterprise creates an incentive to produce quality and accurate data. Additional steps for improving data quality and accuracy in a particular system, application, or business process will be necessary but are not part of this Data Strategy.

4.1.4 Department of Defense Information Sharing Strategy (2007)

In response to a *Quadrennial Defense Review* (QDR), the DoD *Chief Information Officer* (CIO), the *Undersecretary of Defense – Policy* (USD(P)), the *Undersecretary of Defense – Intelligence* (USD(I)), and the Chairman of the Joint Chiefs of Staff developed this DoD Information Sharing Strategy with one of the key tenants being to improve SA.

One approach of the Strategy is Information Mobility of which the operational measure of quality for *security* is mentioned as a key element. A second approach is Information Sharing which lists *veracity* as one of its challenges. Veracity, "…the ability to create relevance and de-conflict potentially conflicting data received from a number of sources," (i.e., the truth as a reflection of real world evidence and not that which is simply believed to be true by a decision maker) provides a second operational measure in the form of *relevance* while also stating a need to validate *accuracy, consistency, authority, currency* and *completeness* in a partial nod to both NCO FC v1.0 and JP 6-0.

4.1.5 Case Study's C2 Facility Concept of Operations (CONOPS) (2008)

The final document reviewed for operational measures was the C3's *Concept of Operations* (CONOPS) (2008) which is a "*statement that clearly and concisely expresses what the joint force commander intends to accomplish and how it will be done using available resources"* per the DoD dictionary. The operational C2 cycle consists of four phases which occur simultaneously across all organizational mission sets and includes *monitoring*, *assessing*, *planning*, and *execution* of orders as required. Within the case study C2 facility, this cycle is a 24 hours-a-day, 7 days-a-week activity carried out by a core group of watch standers with assigned tasks and designated information system tools.

In the monitoring phase, these decision makers are responsible for gathering information received from all sources with the objective of maintaining SA of the organization's *operational environment* (OE). Per the CONOPS, the process of deriving OE awareness is supported by *accurate* and *timely* intelligence collection which constitutes two of the seven operational measures of information quality criteria identified in JP 6-0.

4.1.6 Summary of evidence of operational measures from document reviews

A summary of evidence collection regarding the operational measures for information quality criteria discovered in the reference documents are listed in **Table 4.3**. The most immediate observation from the table is the lack of consistency across the documents. While this listing of information quality criteria is unique to DoD and not an absolute, it must be noted that the documents are from a variety of DoD organizations (e.g., Joint Staff, Office of the Secretary of Defense, etc.) over a period of six years (2003-2008). Such inconsistency is unfortunate, but not unusual within DoD policies given the federated nature of the U.S. military's management of IS and cyberspace operations.

Table 4.3 Summary of Evidence of Operational Measures from Document Reviews

	JP 6-0	NCO CF v1	DoD NCDS	DoD ISS	CONOPS
Accuracy	X	X		X	X
Relevance	X	X		X	
Timeliness	X	X			X
Usability	X		X		
Completeness	X	X		X	
Brevity	X				
Security	X		X		

4.1.7 Evidence of quality meta cue requirements from document reviews

Documenting evidence of DoD information quality cue requirements proved to be problematic. There is some history on this from my previous research efforts. After presenting the results of my work on the recommended adoption of the *National Institute of Standards and Technology* (NIST) security control for quality into the list of DoD *information assurance* (IA) controls (Morgan, 2007a), I was informed by several senior members of the DoD's IA program that they had no desire to pursue such a requirement.

Their justification for not doing so, defined *criteria* somehow equating to *standards* confirmed a false but widely held notion within DoD that requiring an ability to measure data quality criteria via meta-data to facilitate cueing somehow equates to the setting of mandatory information quality standards for DoD. Additionally, attempts to include a security control for data quality during recent reforms have been unsuccessful due to the mistaken belief by many that quality is governed via some unknown process in IA.

4.2 Evidence of FFC Quality Meta Cues from Observations

Use of the case study methodology provided me with the latitude to conduct evidence collection as both an investigator and an active participant in the C2 process being documented. This dual role allowed me to act both as an operator and to collect evidence within a highly restricted military facility normally closed to such research.

4.2.1 My direct observations

The environmental conditions of the case study C2 facility, referred to hereafter as the *Command and Control Center* (C3) at U.S. Major Command, are typical for most fixed military C2 sites. See **Figure 4.3** as an example of a modern DoD C2 facility.

Figure 4.3 NORAD/NORTHCOM Operations Center (www.defense.gov)

From the first moment of entering the C3 at USMAJORCOM and observing the vast array of wall size displays intermingled with dozens of decision makers at individual workstations (some working with four and five computer monitors), my initial impression as a watch stander was that of both extreme isolation and information overload simultaneously as we were all equally sequestered into this secure and confined facility, yet with access to hundreds of applications providing a 24/7 stream of global information.

Returning to my research question, "*How do decision makers perceive the quality of the information provided them by indirect observation systems?",* and armed with the operational measures for information quality criteria culled from the document review, I spent 40 hours inspecting C3's indirect observation systems over a period of ten days across various shifts and tasks to document meta cues for information quality criteria.

During my period of direct observation, I documented FFC based information quality meta cues for *relevance* in the form of user generated search tables called *user defined event logs* (UDELs) which the SKIWeb tool automatically filters and displays.

- **Strategic Knowledge Integration Web (SKIWeb)**. See **Figure 4.4**.

SKIWeb was developed to provide a net-centric, asynchronous, collaborative event management capability in order to improve situational awareness for all Secure Internet Protocol Router Network (SIPRNET) and Joint Worldwide Intelligence Communications System (JWICS) authorized users. The SKIWeb vision is to organize event-based information into a globally accessible, operationally relevant, near real-time database enabling users to quickly and collaboratively share data and adjust as necessary (www.fbo.gov).

FFC
Interface

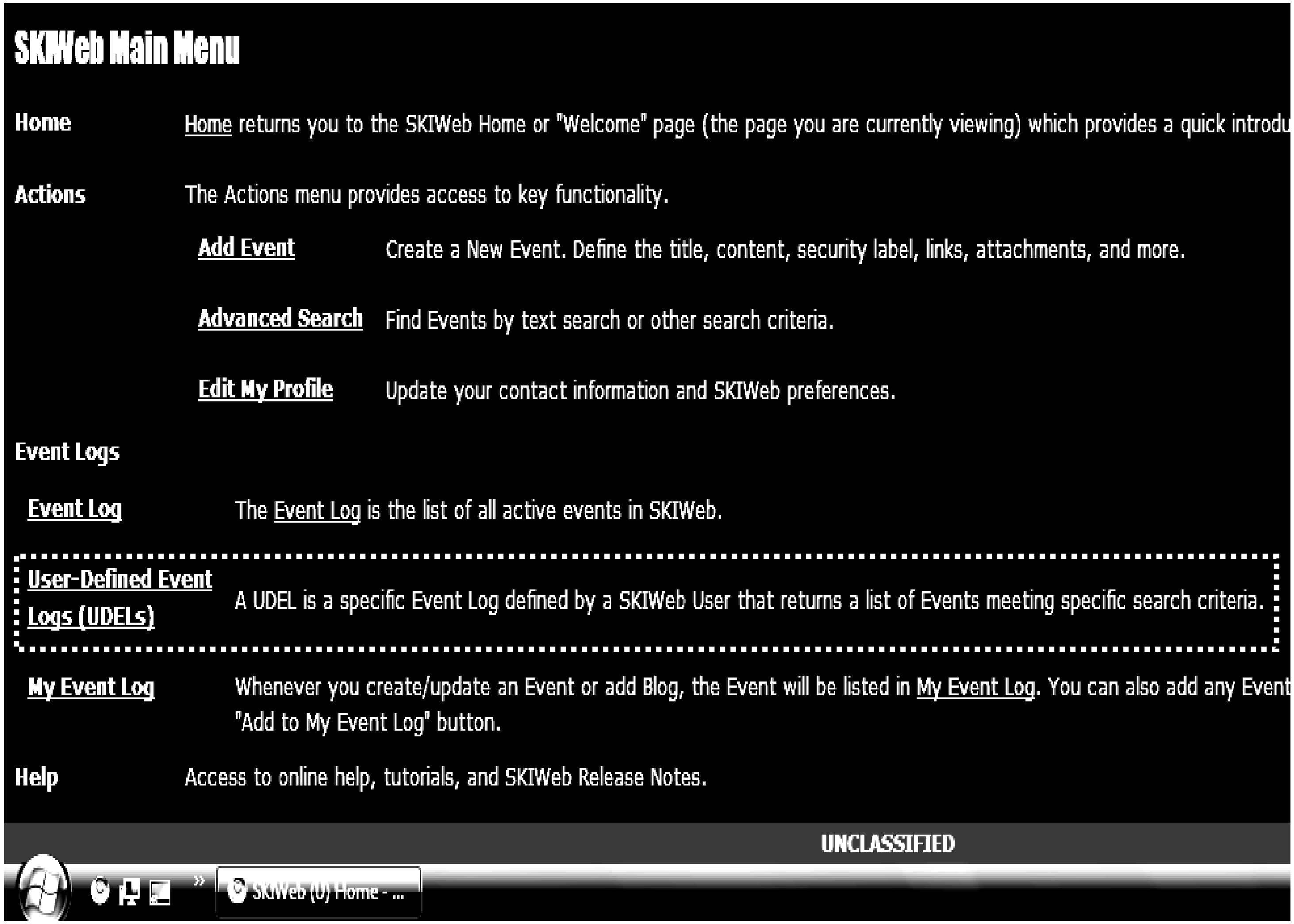

Figure 4.4 SKIWeb Screen Shot with FFC Interface Boxed (https://skiweb01.ngtechnotes.net

Information quality meta cues for *security* were also observed in the form of an automated display designed to reflect a telephone's dynamic classification level. As the security process applied to the information changes, so does the visual cue on the display.

- **Secure Terminal Equipment (STE)**. *STE is the current standard for dial up type secure multi-media communications. The terminal is NSA certified for operational traffic at classification levels ranging from unclassified through top secret sensitive compartmented information (TS/SCI)* (www.l-3com.com).

And lastly, information quality meta cues for *security* in the form of dynamic security access levels (SALs) were displayed at the top of a STE-like telephone system.

- **Integrated Services Telephone v2 (IST-2)**. *The top row of the LCD display is used, in general, to display switch-supplied information (Automatic Number Identification (ANI) and Security Access Level (SAL)) and the date/time. If a communication failure occurs during operation, a message ("Non-Secure Failure", e.g.) will be shown in the display to notify the user of such* (www.telecore.com/products/ist2.html).

4.2.2 Summary of direct observations

A summary of my direct observations made of the external aspects of indirect observation systems within the C3 for each information quality criteria is listed below in

Table 4.4 Summary of Evidence of FFC Quality Meta cues - Direct Observations

Accuracy	No FFC meta cues observed.
Relevance	FFC meta cueing process observed on SKIWeb.
Timeliness	No FFC meta cues observed.
Usability	No FFC meta cues observed.
Completeness	No FFC meta cues observed.
Brevity	No FFC meta cues observed.
Security	FFC meta cueing process observed on STE and IST v.2.

4.2.2 My participant observations

In conjunction with the development of my research proposal and evidence collection protocol, I became a watch stander in the C3 at USMAJORCOM in order to improve my own understanding of its complexities and better shape my research objectives through direct observation and participation in the decision environment.

Initially, I was assigned a position as the deputy facility supervisor and maintained proficiency at this task for six months. The position acted as both a task manager to subordinate watch standers and an information "gatekeeper" to senior leadership while providing me with a great deal of insight into the higher level (i.e. macro) tasks of the operational command and control cycle. These tasks include:

- Receiving, maintaining, integrating, and displaying data from all sources;
- Monitoring the status of global actions, critical events, and crisis areas;
- Monitoring physical environmental conditions;

- Monitoring status of friendly forces, and;

- Monitoring status of adversary forces (CONOPS, 2008).

Along with confirming my initial direct observation cues, I documented cues for *relevance* with AMHS automated message profiling using the tool bar *preferences* icon.

- **Automated Message Handling System (AMHS)**. See **Figure 4.5**. *This system was designed to distribute message traffic using Internet Protocol capabilities being fielded throughout the government. The system also provides automated message profiling via the user tool bar 'Preferences' function* (www.telos.com).

4.2.3 Summary of my participant observations

A summary of my participant observations made of the indirect observation systems within C3 for each information quality criteria is listed in **Table 4.5**.

Table 4.5 Summary of Evidence of FFC Quality Meta cues - My Observations

Accuracy	No FFC meta cues observed.
Relevance	FFC meta cueing process observed on SKIWeb and AMHS.
Timeliness	No FFC meta cues observed.
Usability	No FFC meta cues observed.
Completeness	No FFC meta cues observed.
Brevity	No FFC meta cues observed.
Security	FFC meta cueing process observed on STE and IST v2.

FFC Interface

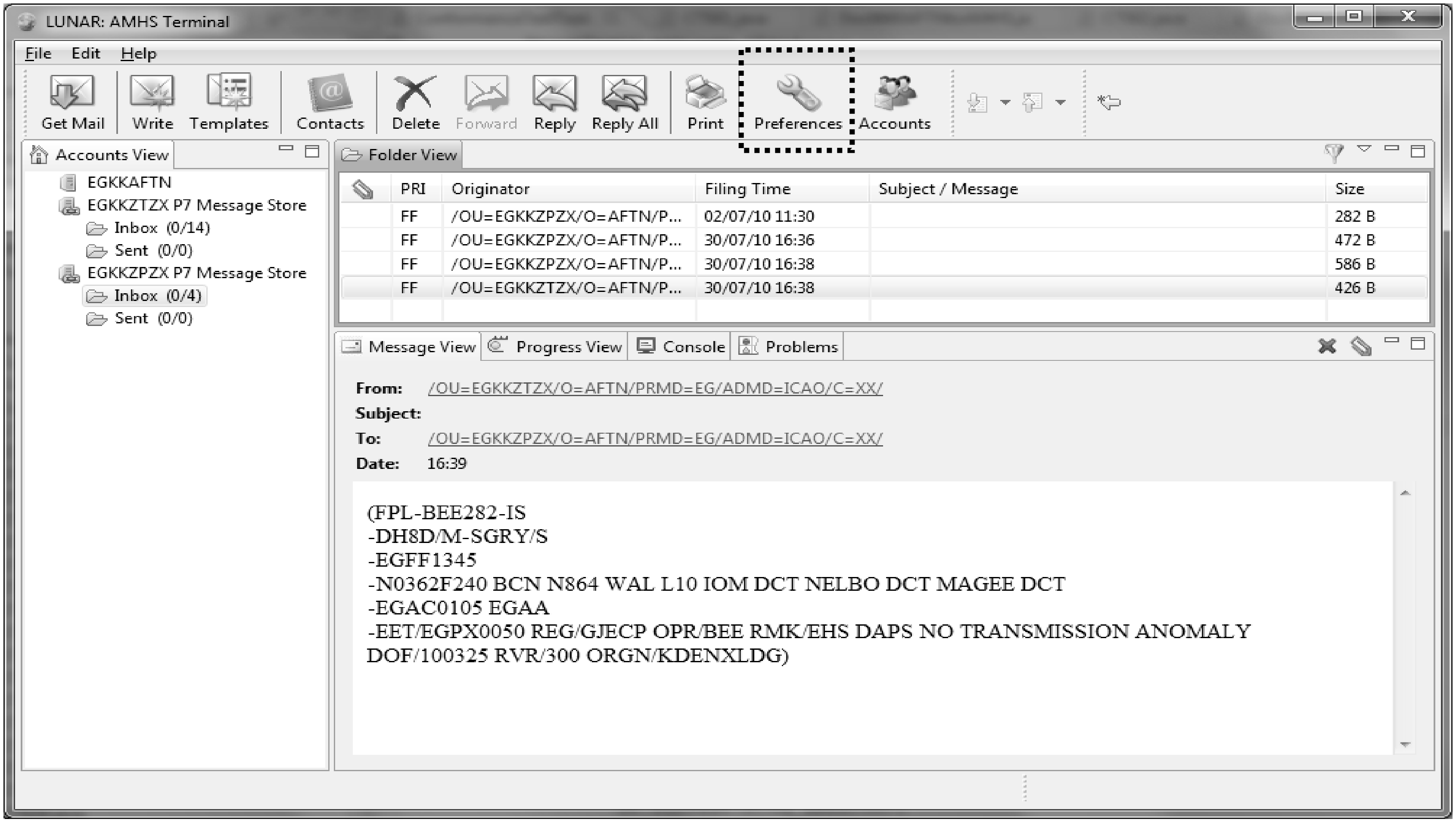

Figure 4.5 AMHS Screen Shot with FFC Interface Boxed (www.copperchase.co.uk)

4.3 Evidence of FFC Quality Meta Cues from Interviews with Decision Makers

4.3.1 Formal survey

The first evidence collection tool I utilized to conduct interviews was a university approved formal survey. Per Yin (2009), formal surveys provide qualitative data regarding the case study by targeting watch standers within the case being assessed. While decision maker perceptions of information quality meta cues in C3 may not always be taken as a measure of the existence of such cues, it is an additional component in the overall task of evidence collection.

Between 23 September and 04 October 2010, *49 individual watch standers* were independently given the survey without any further prompting except to clarify any procedural issues the participant may have had regarding the survey. Participants were also asked not to discuss the survey with anyone until the completion of the case study assessment. Survey inquiries provided to the watch standers consisted solely of the survey question below in **Figure 4.6**.

> *Does your workstation provide indications for any of the seven information quality criteria listed in Joint Publication 6-0?*
>
> *If yes, identify the criteria provided and describe the indicator.*

Figure 4.6 Survey Question

To assist decision makers not fully aware of the DoD information quality criteria and to provide a uniform set of criteria definitions, the list of information quality criteria from JP 6-0 (**Figure 1.1**) was also provided to each participant as a reference.

Participant 1 first identified four distinct examples of web based FFC information quality meta cueing utilized at watch stations in the C3. These included the publicly available *National Oceanographic and Atmospheric Administration* (NOAA) *National Weather Service* (NWS) webpages (see **Figures 4.7 and 4.8**), the commercially available WeatherTAP.com webpage (see **Figure 4.9**), and a DoD secure log in web based application to be referred to in this case study as Application 1.

While the first NWS and WeatherTAP webpages both offered information quality meta- cues via email and text alerts based on decision maker information quality criteria parameters for *relevance* preloaded into the user's profile, the second NWS and Application 1 provided visual and audible information quality meta cues for both *relevance* and *timeliness* based on task requirements. For example, if data for a specific type of event exceeded the user's requirement for timeliness, both the second NWS and Application 1 webpages would cue the user by automatically altering the color of the screen icon or text on the system's user interface (e.g., data < 5 minutes old in green, etc.)

Participant 20 first identified the *Defense Red Switch Network* (DRSN) telephone *security access level* (SAL) indicator as an example of an information quality criteria meta-cue for security. This is similar to the STE and IST-2 mentioned in section 4.2.1.

- Defense Red Switch Network (DRSN). *DRSN is the DoD's global senior level secure voice telephone and conferencing system. It also employs multilevel precedence and preemption (MLPP). In addition, the network passes security access levels (SALs) between users as a further means of verifying end-to-end security and allows processing of calls and conferences from Secret to Top Secret.*

FFC Interface

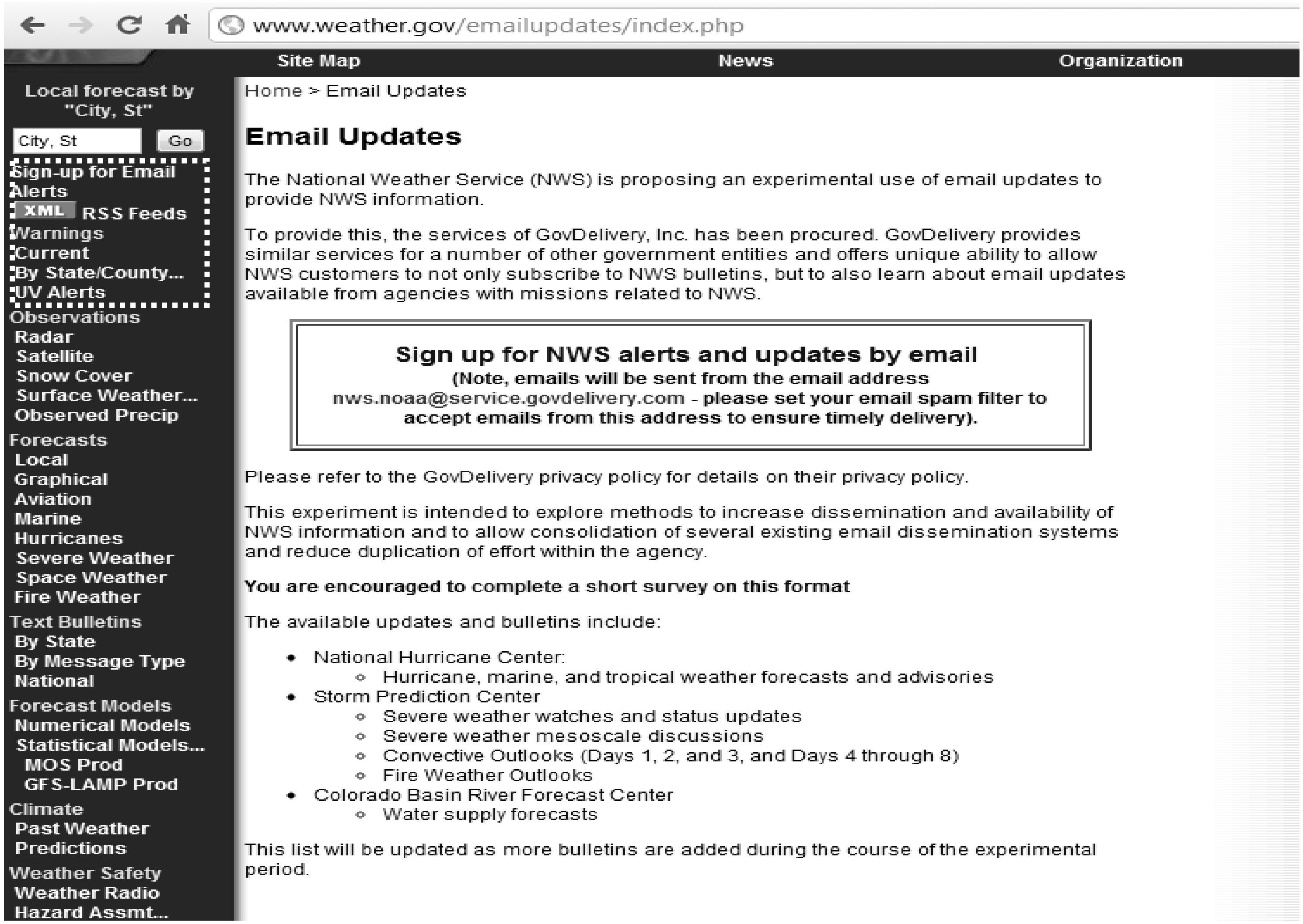

Figure 4.7 WeatherTAP Screen Shot of FFC Interface (www.weathertap.com)

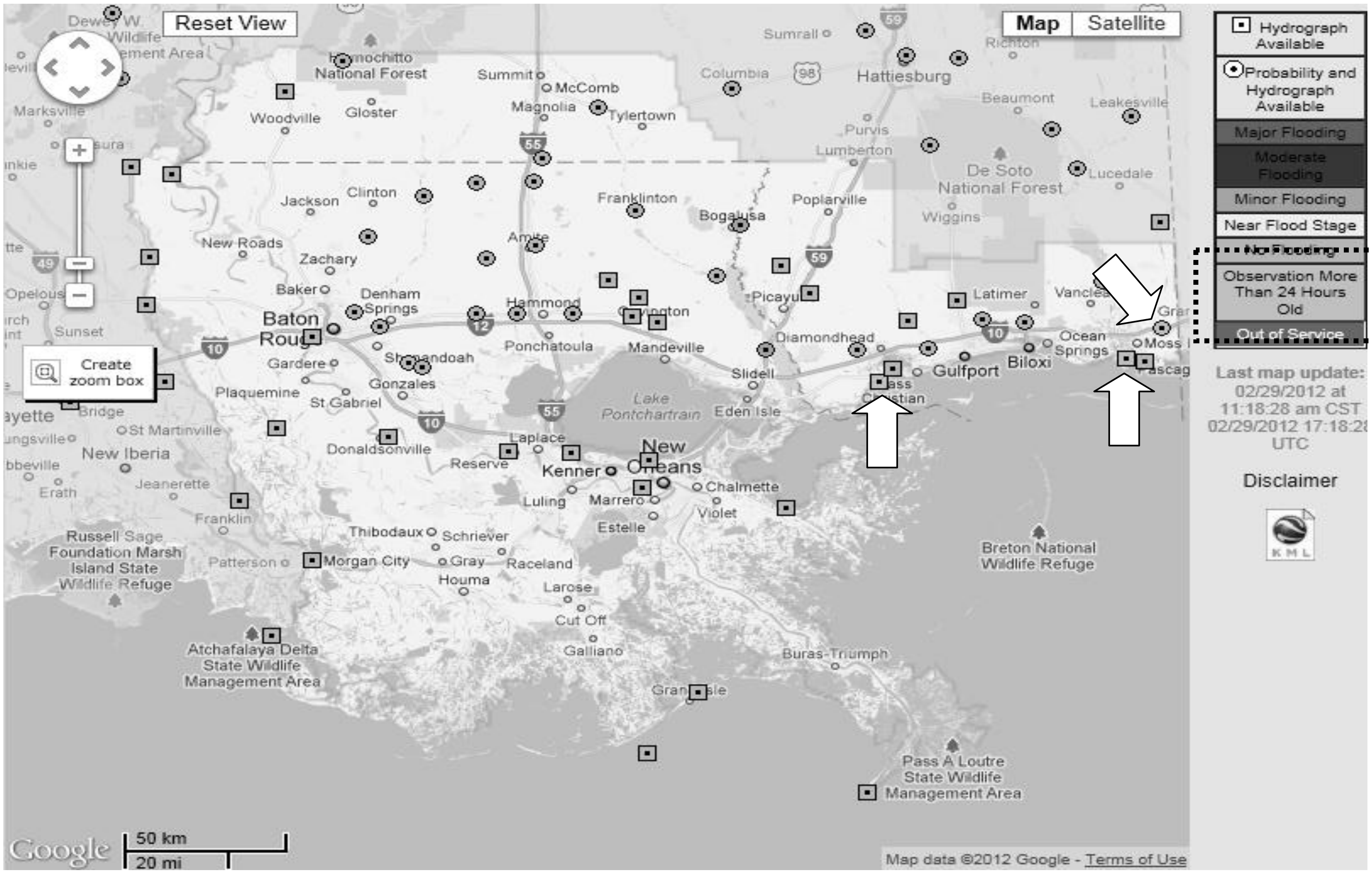

Figure 4.8 NOAA NWS Screen Shot with Color Coded (Gray) Timeliness Meta Cues (www.shr.noaa.gov)

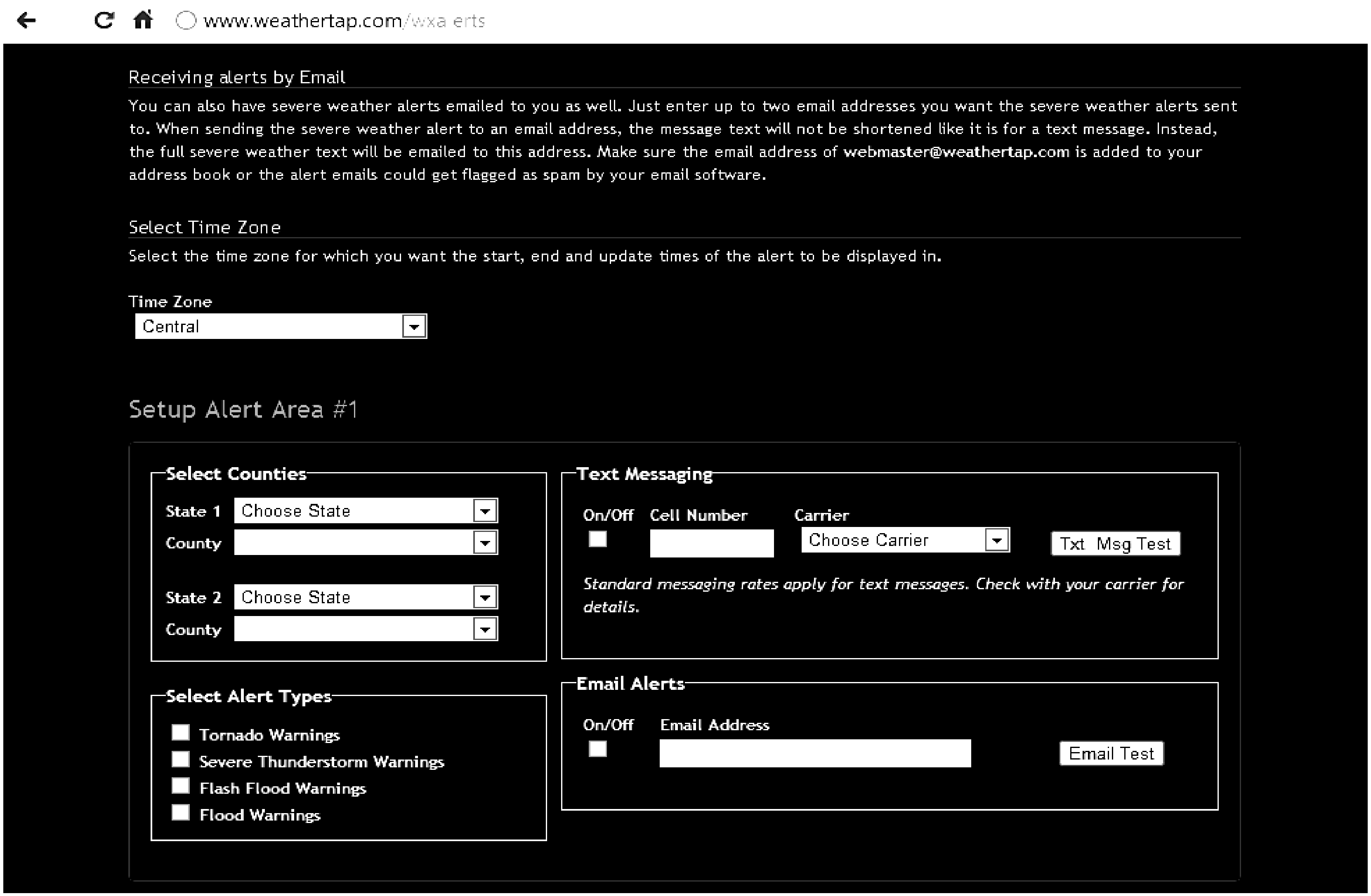

Figure 4.9 WeatherTAP Screen Shot of FFC Interface (www.weathertap.com)

SCI. Each call can be individually class-marked by importance, which then controls access to network resources.

(www.disa.mil/news/pressresources/factsheets/drsn.html)

4.3.2 Summary of evidence of FFC quality meta cues from formal survey

Of the 50 participants evaluated, 16 were able to identify nine unique processes at their workstations which produced from one to five meta cues for information quality criteria. Although no single process produced meta cues for all seven information quality criteria, each JP 6-0 criteria had at least one process associated with it. See **Table 4.6**.

Table 4.6 Summary of Evidence of FFC Quality Meta cues from Formal Survey

Criteria	Observed FFC Meta cueing Process	Instances
Accuracy	- Internal C2 facility Application 2	1
Relevance	- NOAA NWS webpage - WeatherTAP webpage - AMHS - SKIWeb - Internet web based Application 1 - Internal C2 facility Application 2 - Internal C2 facility Application 3 - Internal C2 facility Application 4	3 3 2 6 3 1 2 1
Timeliness	- Internet web based Application 1	3
Usability	- Internal C2 facility Application 2 - Internal C2 facility Application 3 - Internal C2 facility Application 4	1 1 1
Completeness	- Internal C2 facility Application 2	2
Brevity	- Internal C2 facility Application 2	1
Security	- Defense Red Switch Network (DRSN)	1

4.3.3 Focused interview

Immediately following a decision maker's completion of the formal survey, I presented them with a list of approved questions as part of a focused interview. See **Appendix A**. The interview process had two main purposes; 1) provide the decision makers with context for information quality through examples of information quality criteria meta cues, and 2) to repeat the formal survey question in light of the examples.

4.3.4 Summary of evidence of FFC quality meta cues from focused interviews

Following the presentation of the examples and discussions as to what constituted an information quality meta cue, all 50 watch standers confirmed information quality awareness as important to decision making and seven were able to identify additional instances of FFC information quality meta cues beyond what they had identified in the formal survey. See **Appendix A**. These cues are listed below in **Table 4.7**.

Although no new meta cues were identified, the redirection of the original formal survey question not only provided an alternative evidence collection process for triangulation, but also expanded the amount of evidence available for assessment.

Table 4.7 Summary of Evidence of FFC Quality Meta cues from Focused Interviews

Criteria	Observed FFC Cueing Process	Instances
Accuracy	- Internal C2 facility Application 2 - Internal C2 facility Application 4	1 1
Relevance	- AMHS - SKIWeb	4 3

4.4 Summary of Evidence of FFC Quality Cues from All Sources

The full listing of FFC evidence is summarized below. See **Table 4.8**.

Table 4.8 Summary of Evidence of FFC Quality Meta Cues from All Sources

Quality Criterion	Unique FFC Meta Cueing Process Observations	Instances Observed	Collection Tool Used*
Accuracy	- Internal C2 facility Application 2	2	FS/FI
	- Internal C2 facility Application 4	2	FS/FI
Relevance	- NOAA National Weather Service webpage	3	FS
	- WeatherTAP webpage	3	FS
	- Automated Message Handling Systems (AMHS)	7	PO/FS/FI
	- Strategic Knowledge Integration Web (SKIWeb)	11	DO/PO/FS/FI
	- Internet web based Application 1	3	FS
	- Internal C2 facility Application 2	1	FS
	- Internal C2 facility Application 3	2	FS
	- Internal C2 facility Application 4	1	FS
Timeliness	- Internet web based Application 1	3	FS
Usability	- Internal C2 facility Application 2	1	FS
	- Internal C2 facility Application 3	1	FS
	- Internal C2 facility Application 4	1	FS
Completeness	- Internal C2 facility Application 2	2	FS
Brevity	- Internal C2 facility Application 2	1	FS
Security	- Secure Terminal Equipment (STE)	2	DO/PO
	- Integrated Services Telephone (IST) v2	2	DO/PO
	- Defense Red Switch Network (DRSN)	1	FS
TOTAL	**19**	**49**	

***** *DO-Direct Observation, PO-Participant Observation, FS-Formal Survey, FI-Focused Interview***

The table above provides a concise summary of the seven information quality criteria being assessed as listed in Department of Defense (DoD) Joint Publication 6.0, the application the feed-forward control (FFC) meta cueing process was observed on, the number of total instances the 50 watch standers observed the FFC process on the information systems they utilized, and the case study evidence collection tool used to document the evidence.

It must be noted that not all evidence collected is presented in this summary unless directly related to the research hypothesis. Due to the military nature of the case study facility, information collected which identified specific systems not already in the public domain, operational information, or information which identified a specific intelligence or military capability gap has been omitted.

5. ANALYSIS OF EVIDENCE AND LESSONS LEARNED

Evidence collected from the case study and documented in **Chapter 4** verifies my research hypothesis that *meta cues for information quality criteria are provided by feed-forward control (FFC) to military decision makers engaged in command and control (C2) activities as part of their situation awareness (SA) development process.*

5.1 Evidence of Feed-Forward Control

While the evidence from multiple collection tools (document reviews, direct observations, participant observations, formal surveys, and focused interviews) may not be a complete list of all FFC generated meta cues within the facility, it does indicate that none of the 19 documented information quality criteria meta cues identified in this research (see **Table 4.8**) originated from any process other than FFC as each meets the FFC criteria of:

- Residing in parallel to the input and system data flow pathway;

- Utilizing stored plant input requirements in the controller; and

- Providing a control action (e.g. mitigating plant input and/or input cue).

5.1.1 Construct validity

Convergence, or the development of converging lines of inquiry through the use of multiple sources of evidence to corroborate the same fact or phenomenon (Yin, 2009), is a fundamental process in the establishment of construct validity. My use of multiple evidence collection tools provided multiple measures of the same cueing phenomenon.

5.1.2 Internal validity

Supporting the research hypothesis requires more than just documenting examples of FFC used to create information quality meta cues. An equally important step in the analysis process is the establishment of internal validity by addressing rival explanations for information quality cueing. Many of the statements made by the C3 decision makers suggests there were numerous situations which appeared to be processes for FFC information quality cues, but closer inspection revealed they were are not FFC cues at all.

- Discounting non-cues

The first of these situations is the organizational clustering or binning of similar types of information within a defined space that gives the appearance of relevance cueing or filtering. This can be done logically within an IT system (e.g., www.weather.com contains mostly weather related information and is not the result of automated cueing for relevance) or physically through the placement of particular system interfaces at specific work stations (e.g., the weather desk in the C3 uses mostly weather related systems).

The second situation occurs when information quality criteria indicators are used that intentionally or unintentionally mimic dynamic meta cues, but are in fact static. For example, watch standers repeatedly pointed out several displays showing information with what appeared to be meta cues for the information quality criteria of security (e.g., SECRET classification marking on network hardware, interface, and applications).

Dissection of the mechanisms behind these *implied cues* quickly revealed them to be labels (sometimes literally) indicating what information should be vice what is presented.

A third situation identified in the evidence collection process was poor comprehension by watch standers of information quality criteria or policies governing DoD information and thus confusion over what constituted meta cues for information quality criteria. For example, several decision makers attempted to characterize a clock or timing mechanism as a meta cue for timeliness when the reality is that a time piece only provides the baseline from which a timeliness meta cue is generated. All meta cue generation is based upon task requirements for data and information quality, few of which could be identified in writing by the watch standers as part of any watch station's *standard operating procedures* (SOP).

- *The observations of others*

Efforts on the part of the other decision makers can also lead to cueing, but this activity is not tied to an FFC process and represents a tandem variable or *commingled rival* to the case study hypothesis (Yin, 2009). For example, a decision maker with access to an IS may create information quality meta cues identical to FFC, but the cue may have no indication of its origin and appear to others as an automated FFC output. This situation was observed on several occasions in the C3 (e.g., a color change on a status board implying timeliness, an email notice implying relevance or completeness).

Many of the watch standers interviewed discovered examples of such cues only after conducting a self-analysis of information meta cues they originally believed to be of

FFC origin. Most found it disconcerting that other decision makers can so easily mimic FFC meta cues for information quality via their own system inputs and that it is often not readily apparent how to distinguish between the two.

5.2 Case Study Lessons Learned

Observations documented in this dissertation indicate that the lack of a theoretical model incorporating feed-forward control (e.g., the existing Endsley *Situation Awareness Data Flow in System Design* diagram is only an example of various SA information sources) undermines the inclusion of FFC in decision support tools and indirect observation systems created to enhance user SA. Evidence in **Chapter 2** from the literature review showing a limited awareness of feed-forward control and **Chapter 4** documenting the limited use of quality criteria, lack of information quality criteria requirements, and overall lack of information quality meta cues in general strongly supports this conclusion.

Despite nearly 300 reportable systems associated with USMAJORCOM's C3, in addition to a host of non-reportable systems available to each of the 50 watch standers who participated in the case study, to have them document only 19 unique instances of FFC induced information quality meta cueing and only 49 instances overall is a ridiculously low number for an organization engaged in an activity for which poor SA and decision errors could lead to catastrophic national and global outcomes.

I believe the results of this research also confirm that, while the Endsley *Situation Awareness Data Flow in System Design* diagram may be representative of many indirect observation systems, the diagram depicted in **Figure 1.2** is an over simplification of what is often a much more complex information flow process. The omission of critical processes essential to FFC perception meta cue creation at the initial stage of creating decision maker SA can have a negative impact on desired decision making outcomes if such processes are left unacknowledged or are assumed to exist.

So what are the lessons learned from this research? Put simply, information acquired via indirect observation systems often loses its environmental context in the conversion from the real world to data representations of the real world in information systems. Fortunately, feed-forward control can assess the data being injected into our decision making processes and generate meta cues on the quality of the information provided. Equally important is that decision makers must never assume the existence of FFC policies or use of FFC processes to mitigate information quality anomalies and/or provide meta cues to improve decision maker situation awareness.

5.2.1 Impact of the absence of information quality meta cues

Of equal importance to enhancing situation awareness of information quality via FFC meta cueing is decision maker perception of information quality in the absence of cues. In the absence of any information quality meta cue or obvious information quality failure based on knowledge or experience, no evidence was documented indicating decision makers in this case study did anything but <u>assume</u> the information provided was of high quality and conformed to task requirements. Given this tendency, effective implementation of FFC would thus require placeholder meta cues for desired information quality criteria and that they are able to indicate not only the status of particular quality criteria, but also when no information for desired criteria exits.

5.2.2 Findings

There are several significant findings in this case study research from which we can shape our perspective of the DoD information environment:

*- All 49 focused interview participants identified information quality as important in their decision making process (see **4.3.4** and **Appendix A**);*

*- 47% (23 of 49) of interview participants were aware of incidents in the USMAJORCOMMAND operations center that were the results of unavailable data or information quality cues for criteria such as timeliness or accuracy (see **Appendix A**);*

*- Operational measures (e.g., criterion) for information quality are inconsistently applied across DoD policy (see **Table 4.3**);*

- No DoD wide policies were found for the creation of information quality cues;

- No feed-forward control (FFC) process was identified in any DoD document;

- Meta cues for the information quality criteria of relevance accounted for 66% of all FFC meta cues observed;

*- 19 unique FFC processes observed in the C2 facility (see column 2 in **Table 4.8**) accounted for less than 1% of the more than 2100 possible meta cues theoretically available from the more than 300 systems/applications used by decision makers;*

*- Decision makers such as Subject 12 state they "assume data is valid from source" given the lack of information quality meta cueing (see **Appendix B**); and,*

*- Decision makers such as Subject 32 state "I guess I am the tool" given their own poor perception of information quality, the information flow process in general , and lack of automatically generated meta cues for information quality (see **Appendix B**).*

6. INCORPORATING FFC INTO THE INFORMATION FLOW PROCESS

This case study is a continuation of my previous work on issues of information integrity in time constrained decision making (Morgan, 2007) and subsequent applied research into poor data quality impacts on decision maker uncertainty (Morgan, 2007a). One of the major, though inadvertent, outcomes of that work was a realization of the limits of new knowledge related to the IT security risks associated with poor quality information without the benefit of a model to illustrate such knowledge in the context of existing information flow theory. A picture is worth a thousand words and I needed a picture that better represented reality.

Endsley's diagram only shows how some information flows, but I needed something to show the flow paths and processes behind all the outputs we receive, not just the ones observed most often. The epiphany for this idea: I used to manage a very complex IT process which provided DoD decision makers with critical operational information. One day I received a call asking why I was sending them "crap" but when I looked at the displays designed to help me manage the system, everything was green and the output met the format criteria. But that wasn't enough. In reality, the data was useless. Somewhere deep inside the system, something had come undone, some process unhinged and I couldn't perceive it. It was not enough to stop the process, which I would have noticed, but enough to alter the quality of the output so it was no longer fit for use.

6.1 Perception of Information Attributes with Feed-Forward Control Model

I set out discover how meta cue generating is done and how to incorporate it into Endsley's insightful but oversimplified notion of data flow. My initial *Data Flow Model for Indirect Observation* was a good start, although far from complete, and I presented that information flow model with the incorporation of FFC at the annual meeting of the DoD Human Factors Engineering (HFE) Technical Advisory Group (TAG) in 2007.

Feedback was positive and I continued to makes refinements, but it wasn't until I was given the opportunity to work and conduct this case study at USMAJORCOM that I was able to capture critical nuances of the process. A new iteration was presented at the IEEE Systems Conference in 2012 and this version of the *Perception of Information Attributes Using Feed-Forward Control* model, see **Figure 6.1** below, contains the latest refinements based on case study evidence and feedback from my dissertation committee.

This model is a hybrid of Endsley's *Situation Awareness Data Flow in System Design* (1995, 2000) diagram from **Figure 1.2,** Kabamba et al's *Feed-Forward Control Model* (2002) from **Figure 2.3**, and my own observations of the feed-forward control process observed over several years of research. These observations include the FFC required data flow pathways for:

- *Pre-defined output information attribute requirements;*

- *Meta-data associated with pre-defined output information attributes for use by FFC sensors to detect information attribute disturbances in the data flow*;

and,- *FFC control actions directed back to the system's plant and interface.*

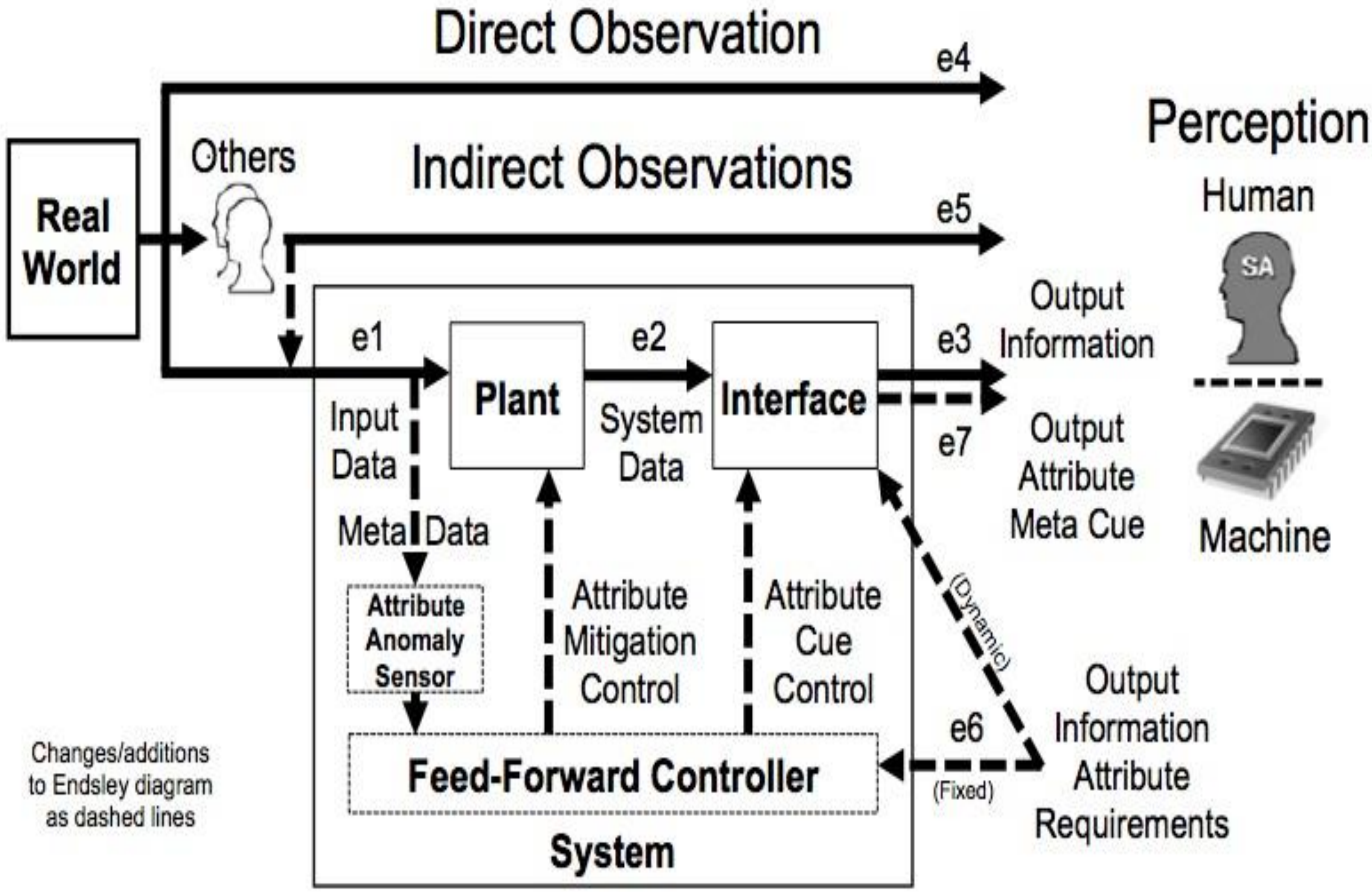

Figure 6.1 Perception of Information Attributes Using Feed-Forward Control

A loss of any of the three inputs would result in the failure of FFC to provide the user critically important meta cues on information quality. An additional pathway for FFC *attribute mitigation control* is provided should the system also be capable of correcting detected disturbances in information quality (e.g., removing or replacing poor quality input data with data that meets or exceeds output attribute requirements).

Retaining flow path nomenclature from Endsley's flow diagram to maintain cohesion, the data/information flows of my model are characterized by one of seven pathways (e1-e7). In order to best understand these interconnected pathways and their associated processes, it is best to walk this new model step by step through a vignette involving a strategic military action being commanded and controlled from deep inside USMAJORCOM's C3. Fortunately for the watchstanders in this fictional but plausible event, some key C3 information systems are equipped with FFC capabilities, as was documented in the case study, to provide enhanced decision maker perception of critical quality criteria associated with a commander's critical information requirements (CCIRs).

6.1.1 OPERATION ARMAGEDDON

Tasked by the President of the United States to defend the Earth in the event of an impending collision with an asteroid capable of altering the plant's atmosphere, weather, or simply laying waste to a large portion of the globe, the commander of USMAJORCOM informs his staff the event they planned for but hoped would never come has arrived: a massive piece of space rock the size of a football stadium has been detected and its track shows a collision with Earth is inevitable.

Almost. Years of planning for just such an inevitability has provided the U.S. with a capability to deflect the path of the asteroid with the construction of a 20 ton nuclear electric powered “gravity tractor” spacecraft and delivery system. Designed to alter the trajectory of an asteroid by hovering near it and letting gravitational attraction slowly but steadily move the object off its projected path towards Earth, tests on the only existing prototype have just been completed and now it is ready to fly.

Not surprisingly, time is of the essence and the launch window for this mission is narrow, only 15 minutes during the mid-day summer heat of Cape Canaveral’s Florida coast. As the launch countdown ticks away on the digital clocks at the launch center, so to do the clocks in USMAJORCOM’s C3 where this strategic military operation is being directed. Years of planning and come down to this moment and there are few risks left unmitigated, but as anyone who has been to central Florida in the summer knows, the area is prone to spontaneous and often violent storms that quickly rip across the peninsula with high winds, torrential rains, and worst of all for a space launch – lightning strikes.

Fortunately for the teams involved, the senior metrological officer (SMO) at USMAJORCOM, call sign “Black Cloud”, is at the C3 weather desk monitoring the flood of remote sensory inputs capturing dozens of physical and information attributes of the environment within 20 miles of the launch site. One of her key weather SA tools is a commercial web based application called *WeatherTAP* and within that application, a display tracking lighting strikes provided by a company called *Vaisala* via their National Lightening Detection Network (NLDN). Below is the current situation as viewed at the various stages of my *Perception of Information with Feed-Forward Control* model.

- ***Environmental data acquired by the system as input data* (e1);**

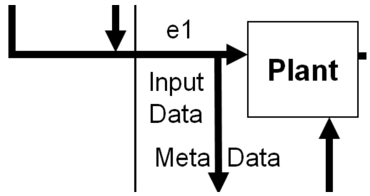

Figure 6.2 Closer Look at Input Data (e1) Flow Path

Figure 6.3 Vaisala's Lighting Strike Input Data Flow Path (www.vaisala.com)

Example – Per the data flow path depicted in **Figure 6.2** and **Figure 6.3** above, "U.S. NLDN consists of more than 114 remote, ground-based lightning sensors. Sensors instantly detect the electromagnetic signals created when lightning strikes the earth's surface. Sensors send raw data via satellite to the Network Control Center (NCC) in Tucson, Arizona. Within seconds, the NCC's central analyzers process information on location, time, polarity, and amplitude of each stroke. Lightning information is sent to users across the country."

The Vaisala process is a system unto itself with an output that becomes data input (e1) processed by WeatherTAP, an independent second system.

- *System data passed from the plant to the interface* (e2);

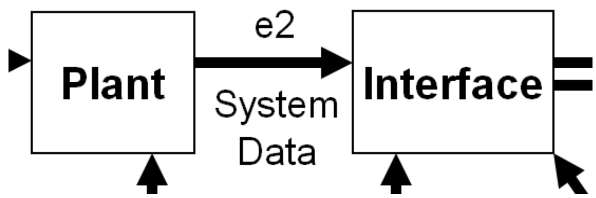

Figure 6.4 Closer Look at System Data (e2) Flow Path

Example – Per the data flow path depicted in **Figure 6.4** above, once the lighting data from Vaisala is sent to WeatherTAP, their data center processes the input via their system's plant and injects this system data (e2) into a graphical interface for use by decision makers. This lightning strike data actually comes in two performance tiers, standard (10 minute latency) and real-time (generally a few seconds latency); however, the application default view of lighting is in the standard display. Real-time data must be specified by the user when the option is enabled.

- *Output information and attribute passed from the interface* (e3) and (e7);

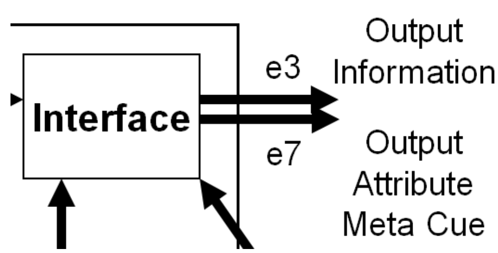

Figure 6.5 Closer Look at Output Information (e3) and Output Attribute (e7)

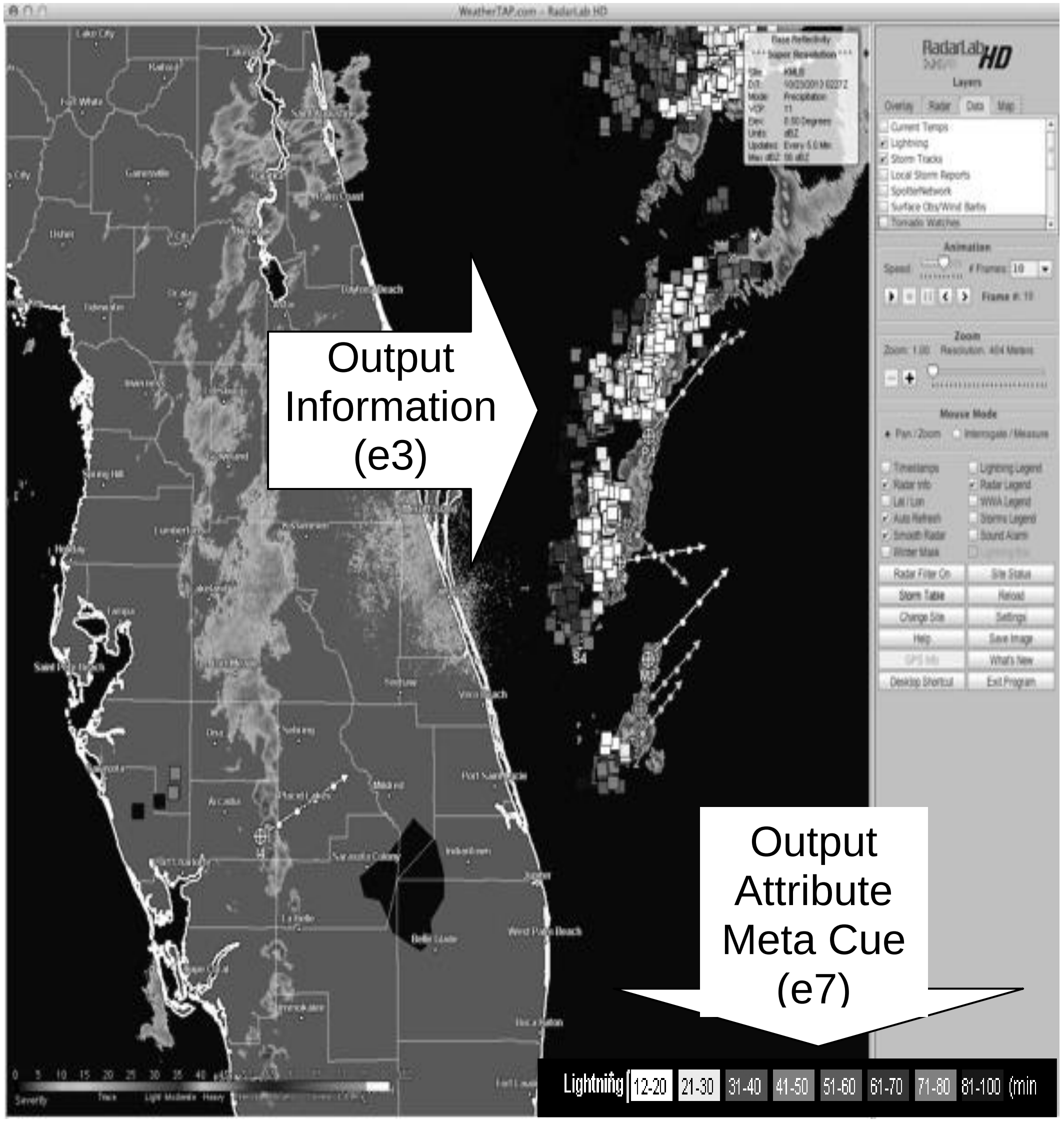

Figure 6.6 Interface Output Information and Attribute (www.weathertap.com)

Example – Per the data flow paths depicted in **Figure 6.6** above, the WeatherTAP interface projects its output for Cape Canaveral to include both the interface's output information (e3) about lightning strikes and the output information's associated attribute (e7) regarding the timeliness of lightning strikes using age based color coding.

- ***Direct decision maker observation of an event*** **(e4);**

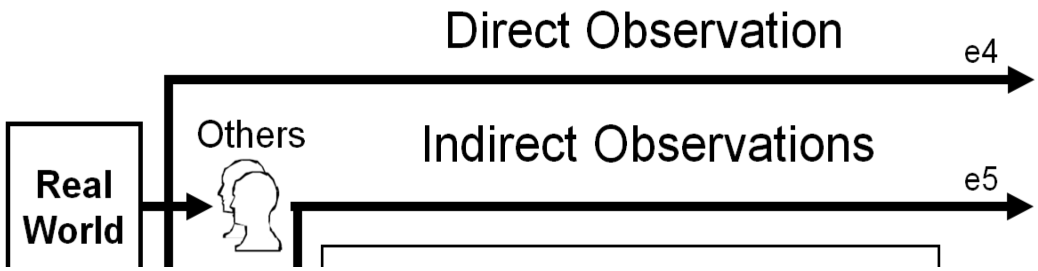

Figure 6.7 Closer Look at Direct Observation (e4)

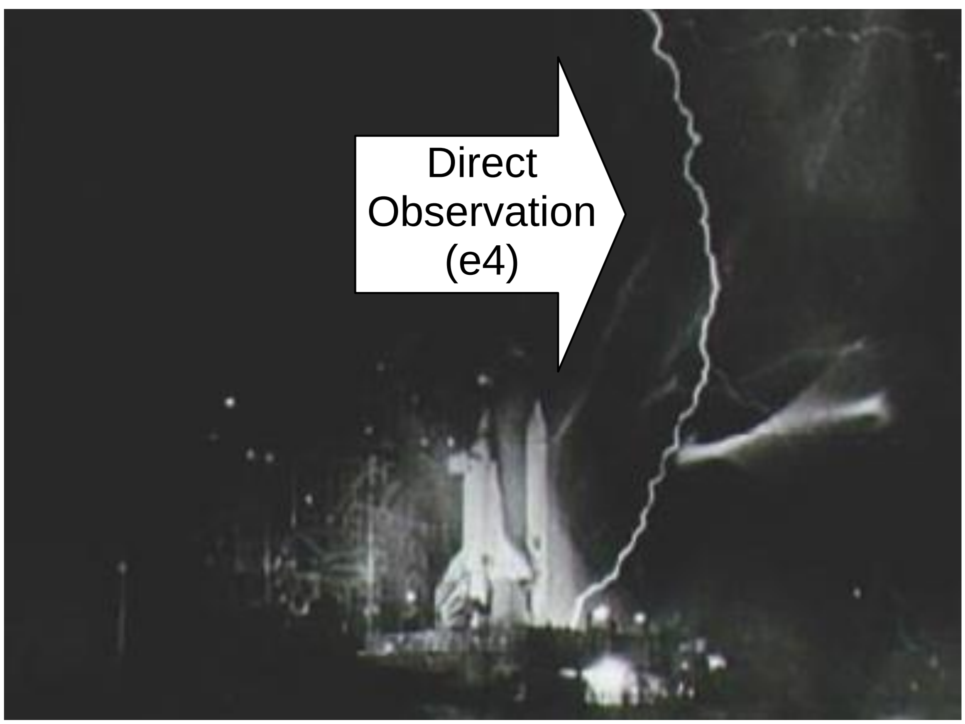

Figure 6.8 Direct Observation of Lightning Strike (http://spinoff.nasa.gov)

Example – Per the data flow path of (e4) depicted in **Figure 6.8** above, an individual could see, hear, and feel the lightning strike depicted using their senses.

- ***Indirect decision maker observation of another observer's perspective* (e5);**

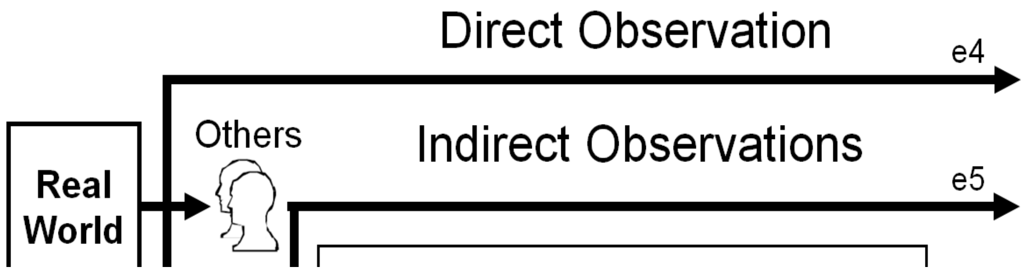

Figure 6.9 Closer Look at Indirect Observations (e5)

Figure 6.10 Indirect Observation of Lightning from Others (www.defense.gov)

Example – Per the data flow path depicted in **Figure 6.10** above, the weather center at the Florida launch site calls Black Cloud in the C3 to report their observations of lightning strikes (e5) and request a 10 minute launch delay.

- ***Decision maker observation of an information quality meta cue* (e6);**

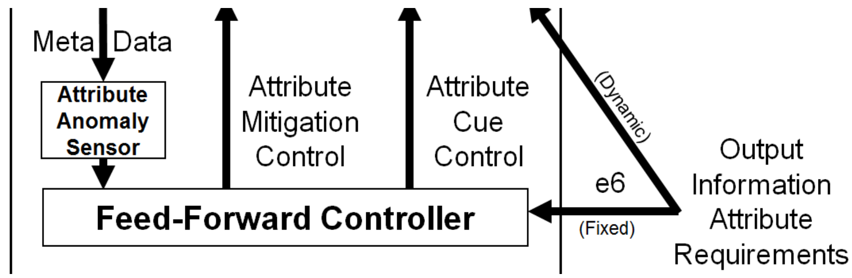

Figure 6.11 Closer Look at Output Information Attribute Requirements (e6)

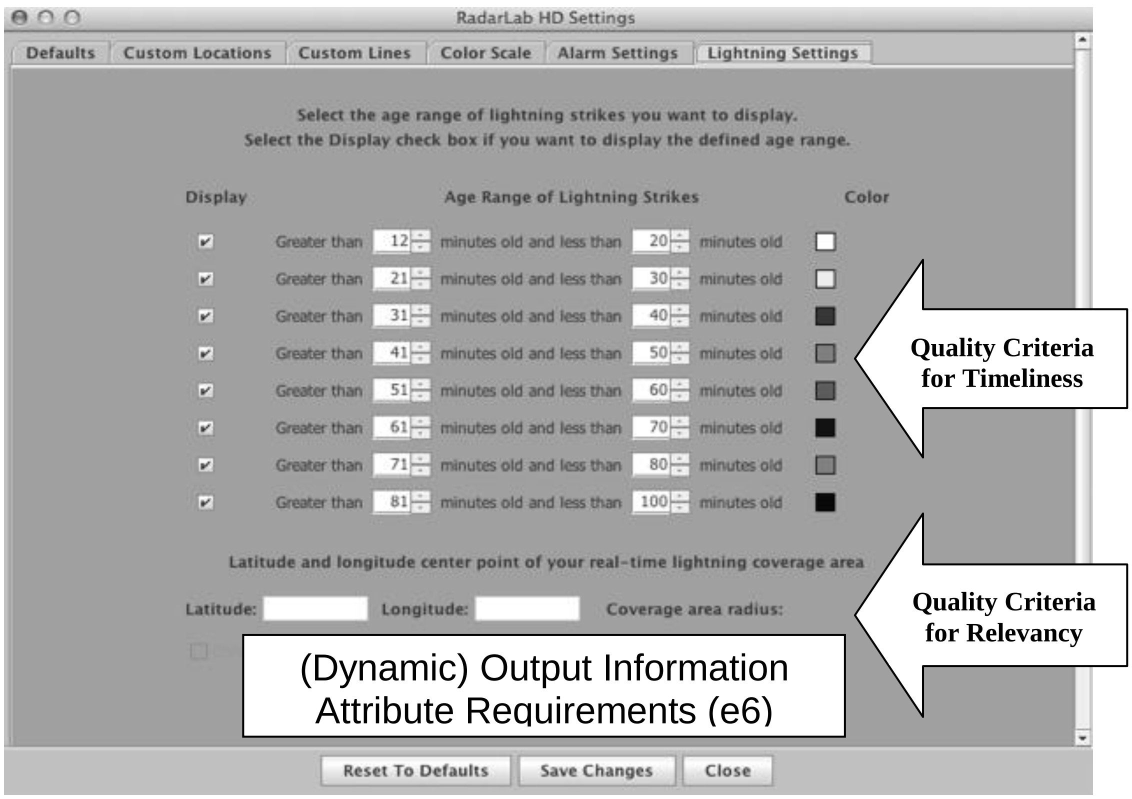

Figure 6.12 Output Attribute Requirements Interface (www.weathertap.com)

Example – Per the data flow path depicted in **Figure 6.12** above, output information attribute requirements (e6) for timeliness and relevancy are loaded into the “Lightning Settings” of the feed-forward controller by Black Cloud via an interface. Depending on the design of the FFC system, users may or may not have the ability to change these requirements depending on the design of the system. The requirements may be “fixed” inside the FFC by process owners.

As described previously in **Paragraph 2.4** and depicted in **Figure 6.1,** when meta-data input disturbances detected by the FFC attribute anomaly sensor exceed the values in the FFC controller, the controller may send an attribute mitigation control action to the plant or data processing area of the system. The specifics of the control action can vary widely depending on the process being executed in the plant, but is generally considered a “data cleansing” which removes suspect data and may also replace it with data meeting or exceeding the desired attribute requirements.

Such control actions can be numerous and varied. For the example above, the feed-forward controller could also generate an attribute cue control signal about the status of the input data based on user requirements. Or, this signal could be the only control action taken depending on the design of the system.

Without the use of FFC to provide an output attribute (e7) for the associated output information (e3), the decision maker could easily succumb to poor SA due to poor perception (Level 1 SA) and a poor decision if the input data, system data, or interface output unknowingly fail to meet essential task output attribute requirements. Such a situation would thus make the output information inaccurate, untimely, or irrelevant, etc., and increase the risk of an operational incident resulting in damaged or destroyed equipment, unintentional loss of mission capability, or the possibility of injuring or killing others.

Of note, all of these decision maker observations (**e3, e4, e5, e7**) are done in parallel with each other and can be combined in any arrangement or sequence. Also, I placed **e1** within the boundary of the system in my model while Endsley had **e1** external to the system in hers. This appears to be a minor conceptual error, otherwise **e1** and **e4** would have represented the same information flow path in the Endsley diagram.

Not to be overlooked, the placement of "Other" observers to the left of the indirect observation system was done to facilitate their observations not only being passed on to the decision maker (**e5**), but to also allow for those same observations to be assessed by a system. An example of this type of observer assessment is the unique FFC process known as the *Method for Assessing the Credibility of Evidence* (MACE) developed by Schum and Morris (2007).

This process allows decision makers to assess not only an observer's observations of the environment, but also the quality of those observations or evidence such as the observer's *completeness* (how experienced is the observer at capturing all desired data), *credibility* (do they have a history of quality observations), and *strength* (how do these observations compare with data records of pervious observations), etc.

But back to the task at hand…saving mankind from certain annihilation by altering the trajectory of a massive asteroid just enough to carry it harmlessly past Earth.

Figure 6.13 Black Cloud Looking Over Output Information And Meta Cues

Black Cloud is watching a massive electrical storm moving towards the launch area via the WeatherTap interface in **Figure 6.6**, but something is amiss. Florida recommends a 5 minute delay due to unconfirmed reports of nearby lightning strikes and taking the launch to the edge of the 15 minute window. Commander USMAJORCOM believes the risk of delay is too great and is about to reject their request when Black Cloud sees the problem: the lightning data on the interface is 12 minutes old. Switching to her personal WeatherTap account with the upgrade for real time inputs, she sees a massive wall of lightning near the pad and confirms a need to delay. Multiple tower strikes are recorded early in the delay, but then it's a launch with 3 minutes to spare. Mission accomplished.

6.1.2 Big Picture Use of Information Quality Criteria

The document reviews conducted during the case study provided a wealth of diverse cyberspace domain attributes and metrics, so mush so as to create confusion do to their distributed and seemingly unrelated nature. To clarify and categorize additional types of information cues possible within warfare domains, I created a tiered diagram of cyberspace domain sub-domains based on common sub-domains and associated attributes for each to include quality attributes identified in referenced documents. See **Figure 6.14** below.

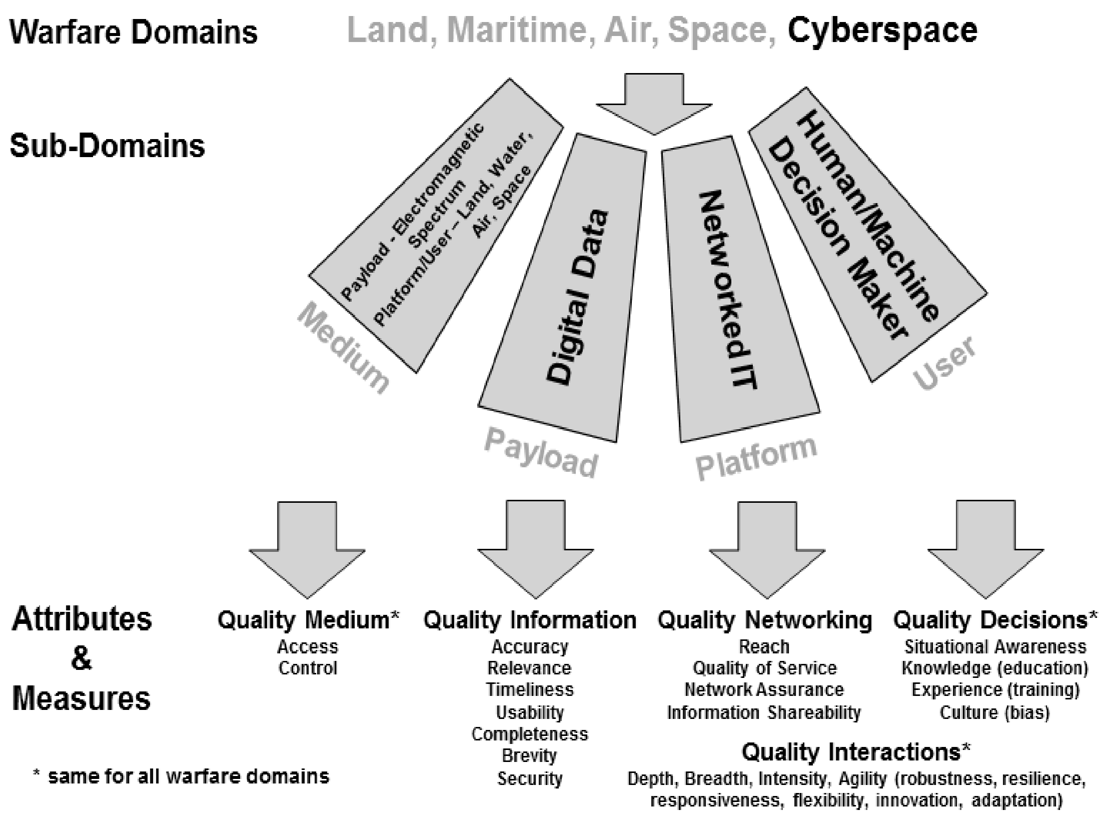

Figure 6.14 Warfare (Cyberspace) Domain Sub-Domains and Attributes

6.2 Recommendations for Future Work

When the use of information quality criteria meta cues as describe by the *Perception of Information Attributes Using Feed-Forward Control* model is accepted and implemented, it is my firm belief this contribution will make possible the development of enhanced data information flow policies, processes, and indirect observation systems.

6.2.1 Recommended DoD policy improvements

The critical need for policies governing the implementation of information quality meta cues and the incorporation of FFC generated meta cues at the organization's operational level became apparent to many of the case study participants during the actual evidence collection activities. None were more impacted than those who realized they operate with systems having no FFC information quality meta cues, were dependent upon cues originating from the observations of others, or were victims of false cues.

The lack of polices regarding information quality, both DoD wide and internal to the case study organization, suggest the need for immediate guidance in the areas of *metrics* and *requirements* to feed *FFC based processes*:

- DoD wide policy in the form of an Information Assurance control (Morgan, 2007a, 2012) for information quality meta-data to be generated as close to the point of data creation or change as possible to include negative responses informing users when such meta-data is not available (would create uniform quality meta data available for continuous input and anomaly assessment by an FFC controller, see **Figure 6.1);**

- DoD wide policy for information system owners and users to regularly document mission or task information quality criteria requirements and incorporate them into each watch qualifications (would define the decision maker's operational information quality criteria output requirements used to populate an FFC controller, see **Figure 6.1**);

- DoD wide system engineering requirements that FFC based processes be assessed in all information system development, deployment, and upgrade phases (would create a mechanism for which systems could be assessed a various points in their lifecycle on the benefit/risk mitigation and return on investment of providing information quality meta cues).

6.2.2 Recommendations to USMAJORCOMMAND

Following the conclusion of the evidence collection phase of my research, I submitted my initial findings to the case study organization's senior leadership for review. The implications of my initial research observations and recommendation to begin immediate mitigation garnered immediate responses from leadership such as:

Information [quality] *monitoring should be part of the day-to-day processes as issues like accuracy, relevancy, and timeliness should never be an issue. Adherence to such policies may be more of a problem, but not having a policy is a bigger problem;* and,

This is one of the biggest questions that a focused group of individuals at the command needs to tackle. Does the command even know what information is needed for *decisions? This has huge payback but some serious analysis/assessment* [is needed] *if it is to produce fruit.*

The concept of utilizing FFC information quality criteria cues to improve decision maker perception found patronage with the command's Chief of Staff (a two-star general/flag officer) who initiated an expanded evaluation process. This process was led by the Chief Information Officer (CIO) and utilized subject matter experts from both the Operations and C4 (Command, Control, Communications, and Computers) directorates.

Ongoing activities by these groups include a range of assessments such as implementation criteria (policy and technical), mission assurance (vulnerability and impact), and cost estimations associated with either retrofitting or imbedding FFC processes and cueing into organizational information systems.

6.2.3 Recommendations for the Intelligence Community

As part of a Director of National Intelligence (DNI) programming effort to better frame DNI resource decisions, a Major Issues Study (MIS) was initiated to assess and analyze a high impact cross-intelligence community (IC) issue and provide feasible alternatives. During the course of one particular study, a lack of knowledge regarding the nature of data was identified with senior decision makers and mission practitioners engaged in analysis, collection, and IT support.

An effort to mitigate this lack of knowledge and understanding of data fundamentals in our expanding data centric operational environment has been undertaken. As part of this activity, I have been asked to write an introductory chapter of a proposed guidebook to *Data in the Intelligence Community* slated for publishing in late

2013. For my part, I intend to discuss data quality issues such as decision maker perception of quality, information flow models, feed-forward control (FFC), decision theory, and the impacts of poor data quality and perception on situation awareness.

The creation of such a text as a fundamental reference within the IC is pivotal to enhance current and future understanding the data dynamics within the intelligence cycle essential to creating high quality intelligence products. Without a sound academic and theoretical foundation in this area of systems engineering, most of those in positions of leadership, and practitioners in general, will lack the ability to make effective decisions.

6.2.4 Recommendations for research

Future implementation of an FFC information quality cue process, as part of ongoing information system replacement and upgrades at USMAJORCOM's C3 and wherever the need to mitigate risks associated with poor data quality, opens the door to a host of short and long-term academic studies focused on a range of topics to include:

- Formalized requirements for decision maker information quality perception;
- Decision performance comparisons between FFC and non-FFC equipped users (topic selected by a *federally funded research and development center* - FFRDC);
- Optimum information quality criteria cue configurations by task or mission;
- Baseline metrics of current information quality levels;
- Metrics for improvements in decision maker perception;
- Metrics for improvements in decision maker effectiveness;
- Enhanced human factor criteria for various types of sensory cues; and
- Expanded cues for criteria such as 'credibility' (i.e., 'trust' in DoD speak).

7. CONTRIBUTIONS

Now what is the message there? The message is that there are known knowns. There are things we know that we know. There are known unknowns. That is to say there are things that we now know we don't know. But there are also unknown unknowns. There are things we do not know we don't know. So when we do the best we can and we pull all this information together, and we then say well that's basically what we see as the situation, that is really only the known knowns and the known unknowns. And each year, we discover a few more of those unknown unknowns.

Donald Rumsfeld, Secretary of Defense, 12 February 2002

7.1 Unique Contributions and Recommendations

The results of this research provided three important and unique contributions to the knowledge of information technology which aids in the perception, comprehension and projection of the unknown unknows mentioned above by Secretary Rumsfeld:

1) *A novel information flow model describing decision maker perception of information with FFC*;
2) *Documented use of feed-forward control (FFC) to generate information meta cues in a military command and control (C2) environment*; and,
3) *Recommendations for U.S. government policy changes to implement FFC.*

7.1.1 An information flow model

To bridge the void between undocumented FFC processes and Endsley's existing data flow theory, I designed the *Perception of Information Attributes Using Feed-Forward Control* Model as a hybrid of Endsley's *Situation Awareness Data Flow in System Design* (1995, 2000) diagram and key aspects from Kabamba et al's *Feed-Forward Control Model* (2002) in conjunction with my own observations of the feed-forward control process.

7.1.2 Documenting FFC

My second contribution is that of documenting the use of FFC in an operational military command and control environment. In the course of conducting the literature review for this research, no academic reference to any existing decision support mechanism currently being utilized to assess system inputs based on task requirements and provide output cues was found which properly classified itself as a feed-forward control process or device.

This is a significant observation in and of itself as it required that I propose research to document a process one would readily expect to find in use, but for which there exists no known operational references. FFC as a process exists as it is routinely used in private, commercial, government and military information systems to monitor and integrate data in information systems; however, FFC as a term to describe such a process in a decision support system has no previous documentation.

As such, documenting FFC usage within the C3 at USMAJORCOM was a critical first step in my research process as it established a baseline from which the overall scope and utility of the process could be assessed and thus support my research hypothesis. The 19 unique instances of FFC identified in this research represent only one piece of the hypothesis; that the FFC processes exist within information system data flow paths. The second piece, that FFC is the only automated quality meta cueing process, was determined from the analysis assessing internal validity.

Lastly, this case study validates my anecdotal observations of the last 10 years in that the use of quality meta cues in U.S. military C2 systems is rare when compared to the total number of cues possible. In fact, the evidence documents this rarity to be extreme with only 19 unique FFC cueing processes producing 49 observations. This represents a less than 1% usage rate of the theoretically possible 2100 information quality cues (i.e., 7 information quality criteria x 300 reportable C3 systems) available for decision makers.

7.1.3 Recommendations for future research

The lack of polices regarding information quality across DoD suggests a need for guidance in the areas of *metrics* and *requirements* to feed *FFC based processes*:

- An Information Assurance control for information quality;
- Regularly document mission or task information quality criteria requirements;
- Use of system engineering requirements that assess FFC based processes.

Additionally, research recommendations to address a host of short and long-term academic studies focused on a range of topics to include:

- Formalized requirements for decision maker information quality perception;
- Decision performance comparisons between FFC and non-FFC equipped users;

- Optimum information quality criteria cue configurations by task or mission;
- Baseline metrics of current information quality levels;
- Metrics for improvements in decision maker perception;
- Metrics for improvements in decision maker effectiveness;
- Enhanced human factor criteria for various types of sensory cues; and
- Expanded cues for criteria such as ‘credibility’ (i.e., ‘trust’ in DoD speak).

And finally, the creation of a composite diagram of the cyberspace domain identifying sub-domains and associated attributes for each to include quality attributes identified in referenced documents.

I look forward to any opportunity to continue research on the topic of feed-forward control to expand the capabilities of decision makers faced with difficult tasks and unenviable responsibilities.

APPENDIX A

The following is the list of approved questions used in the focused interview portion of evidence collection discussed in **4.3.3**. These questions were asked of the 49 watch standers immediately after the formal survey.

1. Do you believe decision maker awareness of data/information quality is important for decision makers in the [USMAJORCOMMAND operations center]? **Yes - 49/No - 0**

2. Are you aware of any data/information quality requirements for your or any other positions in the [operations center]? **Yes - 37/No - 12**

   If yes, list the requirements.

3. Does your workstation provide indications for any of the seven information quality criteria listed in Joint Publication 6-0?
   Yes - 37/No - 12

   If yes, identify the criteria provided and describe the indicator.
   See summary in Table 4.7

4. Do you know of any incidents in the [USMAJORCOMMAND operations center] that were the results of unavailable data/information quality cues for criteria such as timeliness or accuracy? **Yes - 23/No - 26**

   If yes, identify the unavailable data/information criteria.

5. Do you have any recommendations for data/information quality criteria other than the seven listed in Joint Publication 6.0?
   Yes - 5/No - 44

   If yes, state recommendations.

6. How would you improve decision maker awareness of data and/or information quality at workstations in the [operations center]?

APPENDIX B

The following are my direct observations of the participants collected during the administration of the questionnaire and focused interview.

1. Subject 12 writes “Assume data is valid from source” on his questionnaire.
2. Subject 38 states “I guess I am the tool [which assesses quality]” after spending several minutes unsuccessfully attempting to characterize the quality of the information provided by his watch station, describe the information flow process at his watch station, and realize they have no information quality meta cues available to them.

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